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GENETIC GEOGRAPHY

The Development of the Geographic Sense and Concept*

CHARLES REDWAY DRYER

CONTENTS

Introduction: The New Status of Geographers.—Before entering upon the special theme of this address, I wish to note briefly some recent changes in the status of our science and our Association. The late war has taught the world, among other things, that geography is one of the sciences which have a practical bearing upon the largest affairs of the world. Perhaps for the first time in history, geographers have been summoned to the councils of the nation to perform duties which only men with geographical training can perform. Almost every member of our Association has served in some capacity and the details of their war service will be recorded in the forthcoming volume of our Annals. A large number of our members took part in "the Inquiry," conducted by request of President Wilson, under the auspices of the American Geographical Society, in preparation for the peace negotiations, and several of them have served on the expert staff of the Peace Commission at Paris. Others have rendered invaluable service at Washington, and one result is the appearance of new titles and honors, which seem strange in a list of geographers. We may now salute and address, Lieutenant Colonel Brooks, Major Johnson, Major Martin, Captain Huntington, Captain Cushing and others of equal rank. I think all have resumed their peaceful duties except Major Martin, who is geographer to the American Mission to Armenia.

* Presidential address before the Association of American Geographers, St. Louis meeting, December, 1919.

On the National Research Council, which has been made a permanent and official part of the Federal Government, our Association has three representatives. Out of twenty-one members of the Division of Geology and Geography, eleven are members of the Association of American Geographers, viz,: Messrs. Blackwelder, Bowman, Brooks, Davis, Fenneman, Gregory, Grosvenor, Huntington, Johnson, Smith and Vaughan. Geography seems to be coming into its own and to have acquired a better standing among sciences and in the councils of the world.

The Geographic Sense in Animals.—I shall take as a starting point for our flight into space two contrasted statements about geography. The first is that of a boy who said that the earth is a ball filled inside with dirt and worms and covered all over on the outside with nothing but geography. The second is a saying of the very eminent geographer who is also a member of Parliament to the effect that geography is not a science but a state of mind. The common element in the mind of the boy and of the geographer seems to me to be consciousness of his surroundings. Each knows, to use our western phrase, "where he is at."

The sense of locality is shared by many animals and in some is highly specialized. Bees seem to have an unerring sense of the direction and distance of the flowering plants within a few miles of the hive. A squirrel with a nest in a hollow tree acquires an intimate knowledge of the location of the nut-bearing trees in the vicinity and of the arboreal routes leading to and from them. Similar statements may be made about foxes, bears, wolves and other animals. In birds the instinct of locality attains continental dimensions and lies beyond the scope of our understanding or imagination. Millions of them migrate annually, not only between Florida and Hudson bay, but between Alaska and Cape Horn. Somehow they are guided from the home of one season to that of the next through thousands of miles over land and sea. To an inlander the strongest impression made by the sea is its homelessness, its negation of differentiation in space. All landmarks which distinguish one spot from another disappear. One seems to be launched into a spaceless universe and knows or cares where he is no more than the porpoises that follow the ship. Yet the fur seal may be trusted to circumnavigate the North Pacific and turn up on time at the breeding grounds of the Pribilof islands. There is nothing in nature more miraculous than the home coming of the salmon, after years of oceanic wandering, up the Columbia to the lakes of Idaho, where they were born.

The Geographic Sense in Primitive Man.—Primitive and savage men are compelled by their desire for food, shelter, safety and offspring to become intimately acquainted with some portion of the face of the

earth and to acquire a knowledge, definite and detailed as far as it goes, of their environment. It is this awareness of environment in animals and men which I call the geographic sense, primarily a sense of space relation with external objects, but developing inevitably into a sense of other and more complex relations. The geographic sense even has its special organs, located in the semicircular canals of the middle ear. These are the organs of orientation by which we are sensible of our own position in relation to our environment. We are ordinarily unconscious of their function, but the importance of these organs is appreciated when we experience the discomfort and confusion of being "turned around," which may amount in the case of a person who "gets lost" to a dangerous species of insanity.

THE GEOGRAPHIC SENSE IN CHILDREN.—There is no better place to study the development of the geographic sense than in our own homes, provided that the family includes normal children. An active child spends most of his waking hours exploring his environment, in finding out what there is in it and what use he can make of everything he finds. In his world of the nursery it does not take him long to find the shortest road to the toy box, the picture book and the candy jar. Some spring morning, after he has learned to walk, he is turned out of doors and his world suddenly expands enormously. He plunges into its exploration with more zest than Columbus or Magellan ever knew, and every day makes discoveries more important to him than the gold of Peru or the spices of the Indies. And so on, throughout the period of childhood and youth, the human animal continues to expand his consciousness of environment, to learn where things are and the way to get at them. He thus acquires an empirical knowledge of geography more thorough and durable than teachers and textbooks can furnish.

Some writers on pedagogy maintain that the only distinctive geographical discipline consists in the development of this geographic sense, in making it more exact and comprehensive and expressing it in proper symbols; in the reduction to graphic terms of the general consciousness of location, direction, distance, dimensions and contents in space; in short, areal distribution as finally expressed on a map. Pure empirical geography becomes highly developed in some occupations, as in the case of sailors, postal clerks and commercial travelers.

THE FUNDAMENTAL CONCEPT OF GEOGRAPHY.—You meet a man in the street who knows that you have some reputation as a geographer, and he asks you what he conceives to be pertinent questions about Poland or Roumania or Japan. Where is it? How big is it? What is there in it? How do you get there? Such questions indicate possession of the geographic sense and represent a geographical state of mind which is perfectly correct as far as it goes. It seems clear

and beyond question that the psychological foundation of the geographic concept is the sense of distribution in terrestrial space. We must concede the pertinence of the doctrine of Kant that "geography is a narration of occurrences which are coexistent in space."[1] This idea, more sharply put by Bain in the statement that "the foundation of geography is the conception of occupied space,"[2] fits and includes every work generally recognized as geography from Strabo to Ritter and Reclus. With various additions and qualifications, it forms the essence of most of the current and accepted definitions of geography, of which quotation is unnecessary.

Distribution, Static and Dynamic.—Assuming then that the logical and historical core of geography is distribution, the question arises, distribution of what? The favorite term of the definitions referred to is *phenomena,* which would include anything and everything, physical and spiritual. A correspondent suggests that it would mean the distribution of fallen leaves in the forest and of grass blades on the lawn. And why not? It may be granted that a study of the fallen leaves is hardly worth while, yet who can tell? The botanists have been known to take a complete census of all the plants growing in a limited area. Even a study of the distribution of poetry books, musical instruments and works of art is not so absurd as its proposers meant to imply. It might disclose some interesting relation in human geography, including a response to physiographic control. The distribution of ideas and emotions is as truly a part of geography as that of rainfall or corn crops. A map showing in shades of color the prevalence of a belief in transmigration, in the infallibility of the Pope, in the divine right of kings, or any other dogma, doctrine or notion, would be a valuable contribution to human geography. The story of the garden of Eden, which Sir William Willcocks has definitely located,[3] including the tree of life, the serpent, the apple and the fall of man, which forms the basis of the current Christian philosophy, is as characteristic of the physiographic conditions of Mesopotamia as the date palm. Such a story and such a system could not have originated in northwestern Europe, in eastern North America or in the Amazon basin. To determine whether a given problem is geographical or not is easy. The question whether its study is worth while will be answered according to individual judgment and bias.

The Causal Idea in Distribution.—No geographer nowadays is content with a mere knowledge of static distribution in space. The scientific spirit impels him toward the dynamics of distribution, to supplement the questions, Where is it? How big is it? What does it

[1] Immanuel Kant, Physische Geographie, Königsberg, 1802, pp. 1-20.

[2] Alexander Bain, Education as a Science, p. 272.

[3] *Geographical Journal,* Vol. 35, p. 1.

contain? with the more significant question, How came it to be where it is? An inquiry into the causes of distribution gives geography an entirely different aspect and opens the door to relations more comprehensive than those of space. When description of the earth becomes explanatory description no pertinent consideration can be shut out. The causal or scientific element has never been wholly absent from geography. Herodotus, who was as much geographer as historian, uses the method of multiple hypotheses in an attempt to account for the overflow of the Nile[4] and Strabo ascribes the presence of sea shells on land to elevation from the sea bottom.

Influence of Geology.—Scientific geography survived the dark ages in a state of hibernation. It was revived in the 18th century to be nearly swamped in the cosmic schemes of Humboldt. At the middle of the 19th century, under the hidebound teleology of Ritter and Guyot, it was in danger of arrested development and senile decay. From such a fate it was saved by a transfusion of blood and vigor from the young science of geology, which has sprung up by its side, free and comparatively unhampered by tradition. One result of geological training was a demonstration of the futility of Guyot's laws of relief and other empirical schemes, and the organization of the science of land forms, with which the name of the godfather of this Association is so closely connected. It is not too much to say that this was the most effective contribution to scientific geography ever made, and its far reaching results are too well known to be dwelt upon here. Through it, geography was brought for the first time into the quickening stream of modern scientific thought.

Influence of Biology.—In the meantime the Darwinian leaven was revolutionizing not only biology but human thought, and geography could not escape its influence. The distribution of plants and animals in relation to relief, soil and climate and their adaptation to all sorts of elements in their environment, opened a new and fascinating field of research, which was recognized as being of the very essence of geography. Ecology, defined by Haeckel as "the science treating of the reciprocal relations of organisms and the external world," came in to solve some of the most complex problems of biogeography. It was able to give at least a broad general answer to the question, How came this plant or this animal to be where it is? and to throw some light on the question, How came it to be what it is? As plants and animals have in some way become more or less completely adapted to their environments their existence in a given environment being in itself proof of sufficient adaptation to survive; so throughout the habitable world, men are consciously adapting themselves to varied environments. Their culture, or kind and grade of civilization, is

[4] Herodotus, History II, 19-27.

determined by the possibilities of the environment and by the ability with which they avail themselves of these possibilities. In the field of human adaptation the anthropologist, the sociologist, the economist and the historian are incidental students and make valuable contributions, but the man whose special business it is to cultivate this field is the anthropogeographer. The most notable geographic phrase that has appeared in the English language in the 20th century is "physiographic control and organic response," and the epochal books are devoted to the discussion of "the influences of geographic environment," for all of which our Association claims a large share of credit. After all that has been written about the fitting of man to his environment, a biological chemist turns the thesis around and shows an equal claim for the fitness of the environment.[5] This brings us again in sight of the position of Ritter, that each environment has been specially adapted to be the home of its human occupants, and to reintroduce into geographic philosophy a modified teleology.

Geographic Environment.—Through the whole range of geography, the empirical observation and record of the distribution of terrestrial phenomena in space are now supplemented by studies of explanatory relationships, which are found to exist between phenomena of the most diverse categories. In inorganic geography distribution remains the dominant note; in organic geography that note is drowned in the harmonies of adaptation. The effect of the whole concert is an increasing exaltation of the geographic sense. In our expanded and intensified consciousness of environment, the primitive elements of direction, distance and dimensions are absorbed in the concept of diversified contents. It is this condition which I believe Mr. Mackinder meant when he said that geography is a state of mind. When we have acquired the same kind of consciousness of the whole face of the earth that we have of our own home and neighborhood, we will have attained the geographic state of mind, and it will be the logical and psychological development of the mind of the child exploring his nursery and playground.

If we take environment as the key note of geography, the question at once arises sharply, how much of the environment? Must we take into account all its phases or only the physical or natural environment? In a study of Indiana as a geographic environment, the position of the state, its relief, drainage, soil, climate, vegetation, native animals and mineral resources, and the influence of each on the condition and character of the human inhabitants must be given serious consideration. But how much weight, if any, should be given to the fact that the population was orginally derived from two contrasted strains, one from the Carolinas and Virginia through Kentucky,

[5] Lawrence J. Henderson, The Fitness of the Environment, 1913.

and the other from New England, New York, and Pennsylvania through Ohio, each bringing its own peculiar political and religious opinions, social customs and vernacular speech? Are the flight of Quakers from slave holding communities and their influence on the political, religious and educational character of the Hoosier state facts of geography as well as facts of history? A conservative geographer might feel that the admission of purely psychological factors stultifies our name and title by leaving the *ge* out of geography. But as our planet shrinks in physical bulk, it expands in ideal content, the primitive γή, or solid earth, becomes the widest possible κόσμος, or world, and the geographer is forced to become a cosmographer. If he works around the central idea of distribution, he must not omit the distribution of the love of freedom, peace, plain clothes and plain language. If he works around the idea of environment, to ignore the psychological environment would reduce human geography to a headless torso. We have come to the point of admitting a new member to the set of concentric earth spheres and enclosing all in the psychosphere. If any one is troubled by doubts, he may console himself with the thought that any psychological phenomenon, when traced back far enough, may be found to be closely related to some conditions of physical environment. Geographers generally are prepared to give social environment its proper place among geographic influences by the side of physical environment and biological environment and to welcome its elusive complexities to the domain of thorough-going geography.

Organization of Geography.—Out of the rudimentary instinct of the animal, primitive man and child, to place himself among the multitudinous features of the planet, has grown the formidable array of geographic sciences to which the members of our Association are devoted. The accompanying chart is an attempt to display them as a logical system and to show their relations to one another and to the cognate sciences.[6] Each one of these sciences may be the subject of study and exposition as a unit, and the final result is an analysis of the phenomena involved, from which are derived laws of general application to the whole earth. In each case the work can be done by a specialized geographer, who uses the methods and results of experts in the cognate sciences to discover, display and explain the distribution of the features belonging to his department.

Regional Geography.—Yet all this, vast and varied as it is, may be said to be only a preparation for real geography, supplying the raw material with which the master geographer works. His work

[6] This chart is adapted and elaborated from a chart by Lindley M. Keasbey, *Political Science Quarterly*, Vol. 16, p. 79.

THE ORGANIZATION OF GEOGRAPHY

PHASE	Astronomical Geography	Physical Geography	Biogeography	Anthropogeography	Economic Geography	Social Geography
SUBJECT MATTER	The Planet Earth	Atmosphere Hydrosphere Lithosphere	Plants Animals	Genus Homo	Natural Resources	Human Societies
PHENOMENA	Planetary	Inorganic	Organic	Generic	Individual	Social
VIEW	Cosmic	Terrestrial	Vital	Taxonomic	Utilitarian	Institutional
PRINCIPLES	Mathematical—Physical	Physical—Chemical	Physiological	Ethnological	Psychological	Sociological
COGNATE SCIENCES	Astronomy Geodesy	Meteorology Hydrology Geology	Botany Zoology	Ethnology Anthropology	Economics Technology	Sociology History Civics Etc.
REGIONAL GEOGRAPHY	Position Boundaries	Climate Drainage Relief Soils	Vegetation Animals	People	Resources Industries	Politics Education Religion Etc.

lies in the field of regional geography, where a synthesis of the contents of a definite and limited environment may be made. The lines of general geographic research, as shown on the chart, and others which might be added, may be likened to so many river systems, each with its tributary branches, which pour their floods, gathered from the whole domain of scientific research, into the trunk stream of regional geography. The regional geographer can not use it all, but it is all at his disposal and no one can tell *a priori* what part will be needed. This view has been expressed with sufficient directness by Prof. Lucien Gallois.

"In the measure that the sciences have developed, especially the natural sciences, . . . in proportion as our horizon has extended by the progress of discoveries permitting fruitful comparisons, the relations of all these facts, one with the other have been better and better perceived, and this *reasoned whole* has ended in constituting a true science, which is geography, as it is uniformly conceived today, wherever there are geographers."[7]

It is in the regional form that geography has finally attained consciousness of its object, its methods, its function,—of itself. "It is the original rôle of geography," says Lespagnol, "to put in contact the facts which other sciences study in isolation." The same idea has been elaborated by Geddes. "All sciences," he says, "are logical artifices by which we focus our attention upon one thing or aspect, with resulting distortion or disproportion, as through a microscope or telescope. They are geolyses or cosmolyses. Geography is more than a science. It is the concrete synthesis of the world in evolution."[8]

Natural Regions.—Regional synthesis has always been practiced. Geographers have distinguished between earth lore and land lore, between geography and chorography, a word which has unfortunately gone out of use while the thing for which it stands has become more prominent. From the beginning there has been description of countries or nations, having only a political or racial unity. Regional geography is now being placed on a scientific basis by the adoption of natural regions as units. The concept of a natural region has been developed in many lands and languages, but among English speaking peoples credit is due above all others to Herbertson. His scheme of Major Natural Regions, presented to the Research Department of the Royal Geographical Society in 1905, bids fair to remain, with minor modifications, a standard for a long time to come. Until his untimely death in 1914, he never ceased to elaborate the scheme of natural regions and to foster an appreciation of their value. He turned the idea over and over in his eminently sane and fertile mind and illumi-

[7] *Annales de Geographie*, Vol. 14, p. 211.
[8] *Contemporary Review*, Vol. 80, p. 707.

nated it with many shrewd and striking expressions. His geographical essay, "The Higher Units," published in *Scientia* in 1913, presents the ripened fruit of his thought. The general inaccessibility of this essay, as well as its pertinence may, I hope, justify quotation from it here.

"This study of geographical distribution of different phenomena was necessary before the geographer could begin the study of the higher problems of his subject. Not that they were unknown. The question of environment has never been left wholly out of account. . . . It was usually the botanist or zoologist or humanist who undertook its examination from the point of view of some particular problems of his own. . . . Why separate organisms from their environment? Plant associations could not exist without a physical environment. The physical elements and the organic elements are but parts of a whole. The higher unit is not physical nor biological, but geographical. . . . A forest is more than an association of trees and other plants. It has its foundation of rock, its floor of soil, its ambient air, the moisture which penetrates it and the sun's rays which play rhythmically on it. The concrete actual geographical entity comprises all of these. Without all it is not complete. It is a continuous space on the outer limits of the solid layers of the earth, with all which it contains, solid and fluid, inorganic and organic. . . .

"It has been suggested that the term macro-organism should be given to this complex entity, the rocks being its skeleton, relatively stable, the soil itself the flesh, the vegetation its epidermal covering with its animal parasites, and the water the circulatory life-blood automatically stirred daily and seasonably by the great solar heart. . . . If the geographical region is a macro-organism then men are its nerve cells. In some of the huge regional creatures this collection of human units is more or less amorphous, a scattered mass of undifferentiated nerve cells, an unimportant part of the whole. In others it is well organized and specialized as an essential part of it, man having set his mark all over its surface. In fact he is a sort of higher nervous system in it. . . . That such regional leviathans exist and that we each are a part of one is the theme of this paper. The personality of such leviathans, like the personality of men, is another question."[9]

As I understand Herbertson, his concept of geography is an interpretation of the relations existing between genetic groups of land forms, dynamic groups of aerial and oceanic forms, physiological groups of plants and animals, and psychological groups of men, existing together in typical natural regions.

[9] *Scientia*, Vol. 14, pp. 203-212, 1913.

The Earth as an Organism.—The conception of an indefinite number of regional marco-organisms lends a new justification to those enthusiastic and adventurous spirits who have postulated the earth itself as an organism and geography as its anatomy, physiology and psychology. No one has expressed the idea more clearly than Ritter. "There is above all thought of parts, of features, of phenomena, the conception of the earth as a whole, existing in itself and for itself, an organic thing, advancing by growth, and becoming more and more perfect and beautiful. Without trying to impose upon you anything vague and transcendental, I wish you to view the globe as almost a living thing—not a crystal assuming new grace by virtue of an external law, but a world taking on grandeur and worth by virtue of an inward necessity. The individuality of the earth must be the watchword of re-created geography."[10]

Lespagnol treats it with Gallic *verve*. "The earth," he says, "is a sort of organism of which all the parts are in reciprocal dependence. . . . The magnificent accord of the earth and all which germinates and develops on its surface, the harmonious determinism of natural life, give to geography all its beauty and fix its ideal. It endeavors to establish the reciprocal relations of facts of every order, the enchainment of which constitute the life of the earth."[11] It is this "harmonious determinism of natural life" to which Schrader refers in his Herbertson Memorial Lecture of a year ago.

"Man," he says, "must have been a planetary product before becoming a social and moral being—born from dust to rise to thought. Geography, says the old and consecrated definition, is the description of the earth. But that description must not remain only an exterior description and in the body we must try to discern the future apparition of the soul. . . . We must now begin to follow the scientific path which shall perhaps lead the next generations to the great road of scientific harmony between Nature and Man, that still hypothetical harmony, to which Gabriel Séailles, of the Sorbonne, has given the anticipatory name of *Morale Planetaire*."[12]

Henry Wilson, President of the London Society of Arts, gives us a glimpse of transcendental super-geography which he calls geosophy. "There is a geography of thought, a geography of spirit, geography of psychology, of racial influence, a super-physical geography—in fine a geosophy. We want maps of mind, showing the thought and culture currents, idea drifts, spiritual isobars, contours of artistic altitudes."[13]

[10] Comparative Geography, Gage's Translation, XVII-XXI.
[11] Lespagnol, Geographie Generale, p. v.
[12] Franz Schrader, *Geographical Teacher*, Vol. 10, p. 44.
[13] Henry Wilson, *Geographical Teacher*, Vol. 9, p. 196.

This is not all a castle in the air. Mackinder's "Democratic Ideals and Reality" and Fleure's "Human Geography in West Europe" may be taken as successful flights into lofty regions. Let us leave the seers to their visions on the heights, with the assurance that the dreams of one generation may become the science of the next.

THE TECHNICAL LANGUAGE OF GEOGRAPHY.—Geography is one of the oldest of the sciences, but it has had a long adolescence and is still among the youngest in some aspects of development. It is a white-haired centenarian with the speech of a child of ten. It did not and could not develop beyond the stage attained by the physical and natural sciences. Although the mother of half the sciences in existence, geography is dependent upon her daughters for support. She has been stimulated to reach new stages of growth by repeated transfusions of blood from geology, biology, anthropology and sociology. One evidence of juvenility combined with longevity is that geography has never acquired a technical language. This is due in part to the fact that it has, until recently, been able to express itself by the incomparably graphic method of the map. As long as distributions are the subject, the map is sufficient. When other than spacial relationships are to be expressed, adequate words are needed.

The suggestion of Salisbury that the anomalous state of geography in the schools is due largely to the misfortune of being "in English," has much truth in it. The text-book of geography has hardly a term between its covers which can be called technical. The symbols and formulas of mathematics, chemistry and physics and the boulders of Greek origin which sprinkle the pages of botany, zoology and geology are wanting. Geography is printed in plain English which any ordinarily educated person can understand; therefore it can be taught by any ordinary teacher. Fifteen years ago a list of about three hundred geographical terms was being circulated in England, with a view to reaching an agreement as to their exact meaning and uniform use. Most of them were common words like tarn, mere, glen, combe, down, craig, stack, taken from Scotch and Saxon-English, which are very rich in terms for natural features. Nothing, I think ever came of the attempt. Davis has succeeded in "putting over," at least on American geographers, peneplain, monadnock and cuesta, but only with the help of the geologists. We may hope he will succeed with his latest, "hermatapelago" for a sunken reef sea.

ECOLOGY AND HUMAN GEOGRAPHY.—I, for one, cannot help a feeling of envy when I read books like Warming's Œcology of Plants and note the wealth of terms which crowd the pages. Here is a science which has sprung into existence and grown without restraint. It has a more "imperially irresponsible control of language" than Shakespeare or G. Stanley Hall, and an unlimited choice of words.

Plants may be heliophilous or photophilous, heliophobous or sciophilous, anemophilous or entomophilous. There are formations of hydrophytes, oxylophytes, psychrophytes, halophytes, lithophytes, and so on through thirteen classes. To the layman all this is darkness, but to the possessor of everyday Greek, each word throws a searchlight on the plant world. Ecology is the youngest born child of geography and has already brought to the family a new interest and vigor, not inferior to the earlier contributions of geology and general biology. The higher geography is fast becoming a universal ecology and ecological methods are surely applicable to men. Why can not organic geography be unified by using ecological language as far as it is pertinent. I will read Warming's statement of the problems of ecological plant geography, and as I read, I ask you to substitute men for plants, humanity for vegetation, institutions for species.

" The general problem how plants or plant communities adjust their forms and behavior to actual conditions.

" Special problems; 1. What species are commonly associated together in similar habitats. 2. The physiognomy of the vegetation and the landscape. 3. Why each species has its own special habit and habitat. 4. Why the species congregate to form definite communities. 5. Why these have a characteristic physiognomy. Problems concerning the economy of plants, the demands they make on their environment, and the means they employ to utilize surrounding conditions and to adapt their internal and external structure and general form for that purpose."[14]

Can the economic and social geographer devise a better scheme than this? In their demands for " a place in the sun," are not men, as well as plants hekistothermic, microthermic, mesothermic, megathermic and magistothermic? The last require high uniform temperatures and may be the prototypes of the Germans. The fact that such plants are extinct may forecast a similar fate for similar men. Why may not the state of the adapted man be called an *epharmony* and human adjustment to a new habitat *ecesis*? One of the outstanding discoveries of ecology is the existence of plant succession, a regular series of associations which follow one another in the same habitat until a climax of stability is reached. Such a succession of plant associations is called a *sere*. Why should not the successive stages of economic life in the human occupation of an area, as in the Middle West, Indian hunting, white pioneer deforestation, developed agriculture and industrial exploitation, constitute and be known as a sere? Much more complex human seres occur in the older countries. As ecological plant geography, which studies the distribution of growth forms determined by environment, overshadows floristic plant

[14] Eugene Warming, Œcology of Plants p. 8.

geography, which studies the distribution of species determined by heredity, so human ecology opens a wider and more fruitful field than ethnology. I venture to put it up to the human geographer, as a serious practical proposition, that he should avail himself of the methods, formulas and as far as practicable, the language of the plant and animal ecologist. Ecology may do for human geography as much as geology has done for physical geography. I see in the not distant future a great work by some master mind, some Ritter or Ratzel, though I hope his name will be Brown, Jones or Robinson, which will place human geography on a basis as scientific as that on which Schimper and Warming have placed plant geography. If that is ever done, it will be by means of a technical language not inferior to theirs.

A Geographic Inscription.—The use of figurative and poetic language in geographic exposition offers an attractive and unworked field of investigation, on which I had thought to comment, but I must not presume upon your patience longer. Something may be reserved for a future meeting of this Association. I will dismiss the subject with a single specimen suggested by the inscription on a stained window of Geddes' Outlook Tower on the Castle Craig of Edinburgh. It might be placed with an appropriate design on the wall of a geographer's laboratory or lecture room, as symbolizing the ultimate geographic concept.

Orbis Terrarum	Orb of the Earth
Microcosmus Naturae	Little World of Nature
Hortus Vitae	Garden of Life
Sedes Hominum	Home of Men
Solum Historiae	Ground of History
Ager Artium	Field of Arts
Eutopia Futuri	Happy Environment of the Future

ANNALS OF THE ASSOCIATION OF AMERICAN GEOGRAPHERS
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THE BOUNDARIES OF THE NEW ENGLAND STATES

SUMNER W. CUSHING*

CONTENTS

INTRODUCTION.—The purpose of this paper is to treat boundaries geographically. The boundaries of the New England states have been selected as the basis for this study of the geography of boundaries, because New England is compact and important, the boundary features are extremely diversified, and the history accessible and illuminating.

All lines used as state boundaries may be grouped in two great classes: topographic and mathematical. The first refers to boundaries whose position is determined by topographic features; the second, to boundaries that bear no necesssary relation to topography and that can be described in exact mathematical terms. The divisions of the two classes are as follows:

WATER BOUNDARIES

SHORE BOUNDARIES. HOW DETERMINED.—The early charters of the New England district made no explicit mention of the character of the limiting line where the colonies bordered the ocean. But such

* This paper was first prepared some years ago. Its partial revision was almost the last work of Professor Cushing before his death early in 1920. At the request of Mrs. Cushing and the Editor, Professor Ellsworth Huntington has kindly assisted in perfecting the manuscript.

phrases as "the Maine Land from Sea to Sea" would seem to imply the coast line as the limit of jurisdiction. The charter given to Gorges, by Charles I in 1639, included "all the Islands and Iletts lyeinge within five leagues of the Mayne." The Virginia charter of 1606, which included present New England, extended this area to "within one hundred miles of the coast." That of the Massachusetts Bay Company of 1691 included "all Islands and Isletts lying within tenn leagues." Other charters avoided such specific reference to the extent of jurisdiction over the sea.

At the present time, by international agreement, the great seas of the earth are neutral to within one marine league of the islands and continents; the remainder of the water area is within the political domain of the country which it borders. It has been suggested that three English miles were chosen as the limit of political jurisdiction because when the limit was fixed,that was the average range of cannon.[1]

A more probable reason seems to be mere convenience, three English miles, or one marine league, being the unit of linear measure on the water. So the sea boundary of New England, as of all countries bordering the ocean, is now "a line following the sinuosities of the seacoast three miles out, but crossing from cape to cape where there is a great land locked water."[2]

This definition of the oceanic boundary was applied to Canada in Article I of the American-British treaty of 1818. But the diplomats who drew up the document failed to specify what was to constitute a land locked water. This was an exceedingly important point, for Article I refers to the rights of United States fishermen to ply their industry in the great fishing ground along the shores of Eastern Canada.

The question arose: "From where must be measured the three marine miles on any of the coast, bays, creeks, or harbors referred to in the said article?" It was the contention of Great Britain that the three marine miles should be measured from an imaginary line from headland to headland irrespective of the size of the bay in question. The United States took the ground that their fishermen had the right to fish in any bay to within three miles of the shore.

This was the most important of seven questions concerning the rights of United States fishermen on the Canadian coast, submitted to the Hague tribunal in June 1910 for arbitration. The tribunal, after sitting from June to September, established a definite law of international jurisprudence, by announcing that: "the three marine miles are to be measured from a straight line drawn across the body of water at the

[1] Ellen Churchill Semple, A Study in Anthropo-Geography, *Bull. Am. Geog. Soc.*, April, 1908, p. 210.

[2] Albert Bushnell Hart, Actual Government, 3d Edition, p. 348.

place where it ceases to have the configuration and characteristics of a bay;" and further that the term "bay" refers to that part of a land locked water landward of the straight line across it "in the part nearest the entrance" and "at the first point where the width does not exceed ten miles." This new principle of international law when applied to the New England coast technically divorces "bay" from "Cape Cod" in the title Cape Cod Bay and converts the bay into a neutral arm of the high seas. Similarly, Nantucket Sound is not within the jurisdiction of Massachusetts, and some of the light ships in the sound are anchored in water that is not within the jurisdiction of the United States. Boston lightship is similarly located. On the other hand Long Island sound, because its entrance is less than ten miles across, lies within the jurisdiction of the United States and is divided between the political domains of New York and Connecticut.

It seems probable that a still more exact definition of the off shore boundary will be called for in the near future when fishing grounds become more valuable, and when the floating population becomes more numerous.

The shore boundary as now defined is difficult to conceive definitely since it depends upon the seacoast for its position, and the word seacoast is ambiguous. It may mean the water line at maximum, mean, or minimum low tide; or at maximum, mean, or minimum high tide. Again, if the boundary is to follow the sinuosities of the seacoast three miles out, it may be conceived as a line similar to the coastline and three miles distant, or a line no part of which is nearer than three miles to the coastline.

Advantages of Shore Boundaries.—In general, the shore boundary has numerous advantages; it is the most obvious of boundary lines, it requires no survey to ascertain its position, no monuments are needed to designate its course. The shore boundary has a further great advantage over all others in that it is a physical and ethnic, as well as a political boundary. It thus is the most harmonious of boundaries. In the history of New England no controversy has ever arisen over the sea shore as a boundary.

It may be said that the shore boundary has a disadvantage because the coast line may change rapidly, as happens along the coast of sandy islands bordering the outer margin of a coastal plain. Near Atlantic City, New Jersey, one estate may lose several acres in a few years, and another gain as much in the same time. Nevertheless, the changes do not cause a transfer of jurisdiction from one government to another, and so do not lead to disputes, as do changes in the course of rivers which serve as boundary lines.

In times of war, the sea boundary is one of the easiest to defend.

The harbors are like mountain passes; being the only ways of easy access, they make it possible for all the defensive forces to be concentrated at a few points. Macauley emphasizes this advantage in considering countries which are largely bounded by the sea. " Some states have been enabled by their geographical position to defend themselves with advantage against immense forces. The sea has repeatedly protected England against the fury of the whole Continent. The Venetian Government, driven from its possessions on the land, could still bid defiance to the Confederacy of Cambray from the arsenal amid the lagoons." In the case of a very irregular coastline, like that of Maine, however, where the harbors are over numerous the ease of defense is lessened.

In times of peace, the modern development of marine transportation causes a country with an ocean boundary to be close neighbors with half the world, and is one of the best means of promoting commercial prosperity. The extent and character of her coastal boundary has done as much as anything else to build up New England's manufactures and commerce. In short, in spite of the difficulties in the interpretation of the term, shore boundaries possess great advantages and are quite free from the disadvantages which we shall soon see to be common among some other boundary lines.

River Boundaries. Their Types.—The position of a river boundary may be determined by any part of a river, such as the middle a bank, the deepest channel, etc. Moreover, in this paper, a subclass under this head includes boundaries that are determined by reference to a river, for example, " parallel to and three miles north of " a stream. In New England the river boundary takes first place both in length and the number of references made to it in the charters, grants, acts, and agreements.

No other boundary feature offers so many parts that may be taken to determine the position of boundary lines. New England seems to exhaust the list of possible references, as appears in the following descriptions.

River. No Part Specified.—In some cases where the river is inconspicuous in width no part is specified as the boundary, as is illustrated in a part of the northeastern boundary of Maine (3).[3] Here the line goes " Southerly, by the said branch, (the southwest branch of the St. John's) to the source thereof." (Treaty of Great Britain 1842). Another example of this is found in the most southern portion of the New York-Connecticut line, where the boundary begins " in the mouth of a brook or a river called Byram's River, where it falls into

[3] Numbers in parenthesis refer to boundary lines shown on map, page 21.

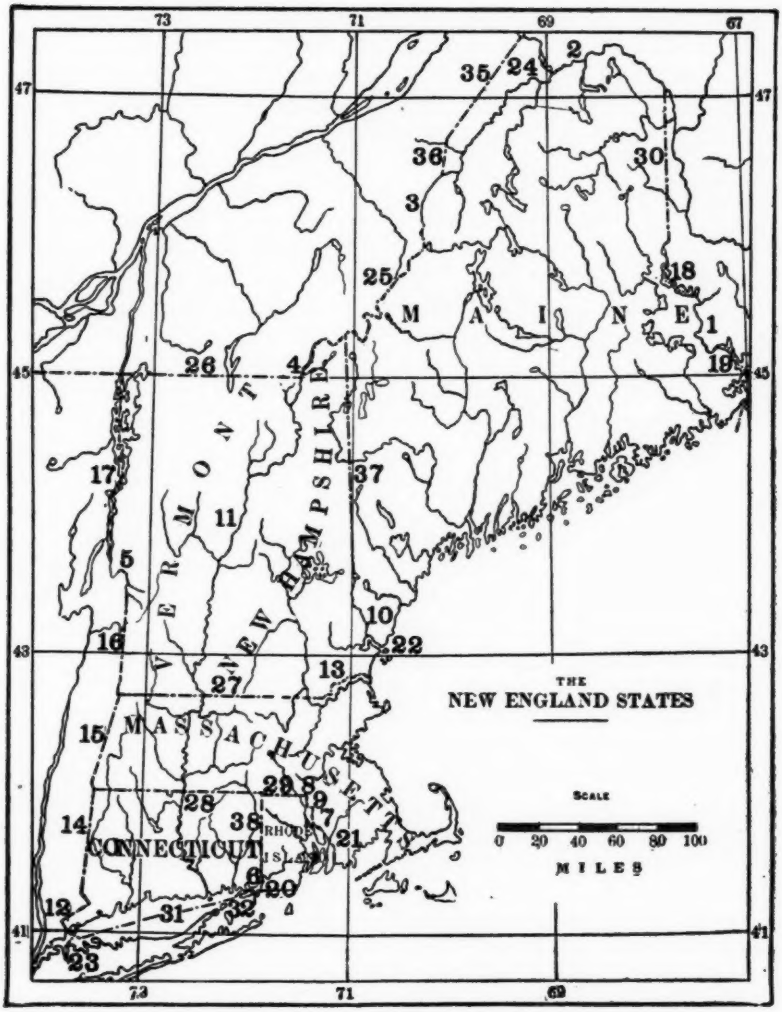

FIG. 1. Location map for points cited in text.

Long Island Sound, and running thence up along said river . . . " (12). (Revised Statutes of New York 1881).

MIDDLE OF VARIOUS PARTS.—The most common part of a river designated for a boundary line is the middle of its course or of the channel. This is the part of the river St. Croix used for a portion of the eastern boundary of the State of Maine. The treaty of 1782 with

Great Britain defined it as "a line to be drawn *along the middle of the river* St. Croix, from its mouth in the Bay of Fundy to its source" (1).

A part of the northern boundary of Maine is a line which runs "*up the middle of the main channel* of the said river St. John, to the mouth of the river St. Francis; thence *up the middle of the channel* of the said river St. Francis, . . . " (2). (Art. I. Treaty of Great Britain 1842). Nearly half of the north boundary of New Hampshire is a similar line (4), it being a line that runs "*down the middle of said stream* . . ." (Hall's stream). (Treaty with Great Britain 1842). "*The middle of the deepest channel*" is the phrase that describes a small portion of the New York-Vermont line in reference to the Poultney river (5). (Act of Congress, April 7, 1880).

Again, the southern portion of the Rhode Island-Connecticut boundary furnishes an illustration of this type, under a wording of new variety. In a charter given to Rhode Island and Providence Plantations by Charles II in 1663, the country was described as "bounded on the west or westerly, *to the middle or channel of a river there* commonly called and known by the name of Pawcatuck . . . , and soe along the sayd river, as *the greater or middle streame* thereof reacheth or lyes upp into the north countrye . . . ." (6).

The Massachusetts-Rhode Island commissioners in 1860 attempted a more specific designation for the same type of boundary when they described a small part of the line between their states (7), as running "*through the center or middle of said Runnin's River as the same is at low water.*"

The southern fourth of the Maine-New Hampshire line, shows the boundary "*passing up the middle of the river* of Newichwannock, part of which is now called the Salmon Falls, and through the middle of the same to the farthest head thereof. . . " (10). (Commissioners' Report of 1829).

A line that follows the midstream, channel, etc., seems to be the most impartial one, if any part of a river is to serve as the line. It was probably on this account that this phrasing was so much used in New England. The great variety of expressions used in referring to practically the same part evidently resulted from a lack of standardized boundary definitions.

River Bank.—When King Charles II of England in 1664 gave to his brother, the Duke of York, "all the land from the west side of Connecticut River to ye east side of Delaware Bay" he established a precedent that eventually determined George III, a hundred years later, to declare "*the Western banks* of the river Connecticut" to be the western boundary of New Hampshire (11). Since the Con-

necticut river is entirely within the jurisdiction of New Hampshire, that state collects revenue from all factories using the river for power even if they are located on the Vermont shore. It also has the responsibility of building and keeping in repair all the bridges to Vermont. (Letter from the N. H. Secretary of State 1910).

HIGHEST WATER MARK.—A peculiar local type of river boundary is found along the eastern border of Rhode Island, where the highest water mark is designated as a boundary. The line follows "*the highest water mark* on the easterly side of Farmer's or Seven Mile River" (8), and "*the highest water mark* on the southerly and easterly side of said Ten Mile River" (9). (Decree of U. S. Supreme Court 1861).

RIVER BOUNDARIES. DETERMINED BY REFERENCE.—This type of line might well be considered under another head since it runs over the land at some distance from the river to which it is related. But as its direction, position, and contour are supposedly determined by a river, it seems best to discuss it here.

The most striking example of this class of river boundaries is the eastern two-fifths of the Massachusetts-New Hampshire line (13). This was described in a declaration of the King in 1740 "as a similar curve line pursuing the course of the Merrimac River, at three miles distance on the north side thereof, beginning at the Atlantic Ocean and ending at a point due north of Pawtucket Falls."[4]

The only other example in New England of a boundary determined by reference to a river is between New York on the one hand and Connecticut, Massachusetts and a portion of Vermont on the other. The Connecticut portion of this line (14) was first described as "parallel to the Hudson and twenty miles distant from it, until the bounds of Massachusetts were reached."[5] Later it was observed that if its course followed the constant, though slight bends in the river "it would be of such an irregular and 'zig-zag' character, as to make it quite unsuited for a permanent boundary between two states."[6] So it was agreed that the line should be a straight line, with a general direction the same as that of the Hudson River, and twenty miles distant from it.

As actually run the line deserves to be classed with mathematical boundaries; and in its relation to the topography of the district it is

[4] Henry Gannett, Boundaries of the United States (3d Edition), *Bull.* 226, *U. S. Geol. Surv.*, p. 48.

[5] S. E. Baldwin, Boundary Line Between Connecticut and New York, *New Haven Historical Society Papers*, Vol. III, p. 278.

[6] *Ibid.*

almost a crest line, and a divide. At the time it was run, it coincided with the *ethnic* boundary between the Dutch and English colonies. So it has the peculiar distinction of coming under six distinct classes of boundary lines. The same characteristics hold throughout most of the northern extension of the New England-New York boundary to Poultney River.

The early coincidence of the ethnic, physical and political boundaries in this region was not accidental. The Indians sold grants of land along the Hudson, above the gorge, to the Dutch and described the eastern boundary as a line parallel to the Hudson and half a day's walk distant. This is practically the crest of the highlands. The Dutch settled their grant and came under the jurisdiction of New Amsterdam which is now New York. So it would seem that topography was the controlling factor in fixing the position of the line.

In Massachusetts the precedent established by Connecticut and New York was followed, for the line is here straight, with termini twenty miles from the Hudson River, so that it follows the general course of the river (15). A nearly similar relation holds in the Vermont section of the line (16).

Advantages of River Boundaries.—The most obvious advantage of a river boundary is that it can be easily described in a treaty and indicated on a map. Moreover, its position is so unmistakable, that no survey is needed to identify it. Again, except where interrupted by falls and rapids so that it can be used for power, a river seldom leads to industrial controversies between the sections which it bounds. Also in times of war the river boundary has to a certain degree the same advantages as a coast with its harbors and a mountain range with its passes. The fording places and bridges like the harbors and passes are but places for the concentration of forces, while the other parts may serve as lines of protection. The New England states have never had occasion to test this use of the river boundary.

All the disputes over river boundaries in New England have resulted from the inadequate wording of treaties, as in the cases where the St. Croix river is mentioned without stating which of the several rivers of that name is meant, or from hostility to accepting a certain river as a boundary because it did not include the right area, which happened when New Hampshire refused to accept the Connecticut as her western boundary. There has been no controversy over the position of the line when once a river was accepted.

Disadvantages of River Boundaries.—Of the disadvantages of the river boundary probably the greatest results from the inconstancy of rivers. The part specified in a treaty is liable to change, be it

the middle of the river, the main channel, the deepest channel, one of the banks, or highest or lowest water mark, and with a change may come controversies and inconveniences. This is especially true of rivers meandering in broad flood plains, for such are likely to change their course and transfer much land and possibly people from one jurisdiction to another. The lower Rio Grande has often played such a part and by transferring people from the United States to Mexico or the reverse has well demonstrated the inconveniences of river boundaries. Since New England has been recently glaciated, it has few rivers of this type, and none of these now serve as boundaries.

Rivers with falls, which are valuable commercially, are often sources of disputes if they serve as boundary lines, especially between nations. The Niagara is most famous. In 1910 the water power of the Niagara and other rivers between the Great Lakes led to a treaty between the United States and Great Britain which establishes an international commission to investigate any question arising in respect to the boundary.

Lord Curzon[7] points out that rivers as the creation of nature, in contradistinction to the creation of man, are natural boundaries; but in relation to the natural habits of man, rivers are not the natural divisions, because people of the same race are apt to reside on both banks. This relation of rivers to people, in the early history of New England, nearly established a new state under the title of "New Connecticut," in the valley of the Connecticut river, north of the Massachusetts line. Settlers on one side of the river had closer social bonds with those on the other side, than they had with the colonists over the divide at their backs, and so they desired close political union with them. Outside influence prevented the consummation of this inclination.

A similar relation between rivers and people was responsible for moving the northern limit of New England from the St. Lawrence river, as it was previous to the cession of Canada from France to Great Britain in 1763, southward to a divide.

3. Lake Boundaries.—The northern two-thirds of the New York-Vermont boundary is the most conspicuous example of a lake boundary in New England (17).

Here, in Lake Champlain the line follows the deepest channel between certain islands. The longest and probably the most important lake boundary in the world, that of the United States and Canada in the Great Lakes, with the exception of part of Lake Superior, follows the middle course of the lakes. This seems to be the just position of such a boundary. Conditions in Lake Champlain rendered such a position inadvisable for numerous islands would have been thereby divided between the adjacent states.

[7] Lord Curzon of Kedelston, Frontiers (3d Edition), p. 20.

The Commissioners' report of 1814 describes the line as running "*through the middle of the deepest channel* of East Bay (a small southern arm of Lake Champlain) and the waters thereof to where the same communicate with Lake Champlain; then *through the deepest channel of Lake Champlain* to the eastward of the islands called the Four Brothers, and then westward of the islands called the Grand Isle and Long Isle, or the Two Heroes, and to the westward of the Isle La Motte to the line in the forty-fifth degree of north latitude, . . ."

Another example of lake boundaries in New England is the Schoodic Lakes along the east boundary of Maine (18). No specific mention is made of these in any treaty relating to the northeast boundary. Although they are in numerous places over four miles wide, they are evidently considered a part of the St. Croix river, and hence the boundary follows their middle course.

For a few miles the eastern boundary of Rhode Island is a lake boundary (21). In the Supreme Court decree of 1861, this was described as running southerly along "*The highest watermark on westerly side of South Watuppa Pond,* and of Sawdy Pond, and of the streams connecting said ponds. . . ." The reason for the use of the highest watermark for the line, seems to be that the ponds here mentioned were reservoirs for Massachusetts towns, at the time the boundary was settled.

The more usual variety of lake boundary is illustrated in northern Maine, where the boundary for about twelve miles is through lakes (24). Article I of the Treaty with Great Britain of 1842, describes it thus: "thence up the middle of the channel of the said river St. Francis, and of the lakes through which it flows. . . ."

Sound Boundary.—The southern boundary of Connecticut is a line through Long Island Sound, (23-31-32). For years Connecticut acknowledged that New York owned "all the islands specifically named in her boundary statute" . . . but she denied "that the general dividing line between the States is farther north than the middle line of the Sound."[8] Thus it seemed at one time that the middle line of the Sound would become the boundary, but in 1880 commissioners made the Sound line a series of mathematical lines and their report was ratified. These lines practically follow the middle of the Sound but since no part of the Sound is referred to as a controlling factor in determining the character, position, or direction of this line, they are left for consideration under mathematical boundaries.

[8] S. E. Baldwin, Boundary Line Between Connecticut and New York, *New Haven Historical Society Papers*, Vol. III, p. 287.

Bay Boundaries.—The southern portion of the international boundary between Maine and New Brunswick is a bay boundary (19). In the treaty with Great Britain of 1872, Article II refers to this boundary in these words "a line to be drawn along the middle of the River St. Croix, from its mouth in the bay of Fundy, to its source," and further on, "comprehending all islands . . . lying between lines to be drawn due east from the points, where the aforesaid boundaries . . . shall respectively touch the Bay of Fundy, and the Atlantic Ocean; excepting such islands as now are, or heretofore have been, within the limits of the said Province of Nova Scotia."[9]

The first reference gives merely the starting point, the first part of the second would make the boundary a parallel, and the last part nullifies the first by making it a tortuous line in the bay, winding seaward among the islands. A Board of Commissioners awarded three of these islands to the United States and all the rest to Great Britain. As the line is today then, it has no more specific position as far as its description goes, than a line of separation among islands.

Actually the line is carefully marked by means of white buoys. The need of nice designation is prominently felt here because of the excellent lobster grounds throughout the bay, and the diversity of the laws of Maine and New Brunswick that control the taking of lobsters. Maine protects the young throughout the year by prescribing a minimum length, and New Brunswick aims to conserve the supply by establishing a closed season of seven months, and a minimum length, less than that of Maine, during the open season. This condition offers an opportunity to the fishermen on both sides for increasing their profits, by stealthily ignoring the position of the line.

The southern part of the Rhode Island-Connecticut boundary is a bay boundary (20). It follows the midline of Little Narragansett Bay for several miles. The bay is an open lagoon in a glacial outwash plain into which a river empties. It seems to have been taken to be a part of the river, for the charter of Charles II of 1663, describes Rhode Island as extending to the west, "to the middle or channel of a river there. . . ."[10] with no specific mention of the bay boundary.

The Southern portion of the Maine-New Hampshire line is a bay boundary (22). His Majesty's commissioners reported, in 1735, "That the dividing line shall pass up through the mouth of Piscataqua Harbor, and up the middle of the river," and, "that the dividing line shall part the Isle of Sholes, and run through the middle of the harbor, between the islands, to the sea on the southerly side. . . ."[11]

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[9] A. Gallatin, Northeastern Boundary, 1840, p. 9.

[10] Henry Gannett, Boundaries of the United States (3d Edition), *Bull.* 226, *U. S. Geol. Surv.*, p. 71.

[11] *Ibid*, p. 42.

Bay boundaries are sometimes marked by beacons on land or by buoys in the water. If the latter are used they are liable to be confused with channel markers. So the exact position of the line is difficult to determine.

Bays are usually used for harbors, and most harbors are places of concentrated activity where strict and prompt jurisdiction is required. If a line in a bay is used for a boundary, it tends to prohibit this desirable jurisdiction for vessels may anchor near the line and so be in a questionable position in relation to jurisdiction. The application of quarantine or health laws, or those pertaining to navigation, passengers, fishing, and the like, may be thus hindered. This disadvantage in the bay boundary has been overcome in the Delaware-New Jersey line by permitting each state "to enjoy and exercise a concurrent jurisdiction within and upon" the water of Delaware river and bay.

In the first cession of land from Mexico the United States was careful to obviate this disadvantage by having the western part of the line drawn "to a point on the coast of the Pacific ocean distant one marine league due south of . . . the port of San Diego,"[12]

An advantage of a bay boundary if it be adapted to serve as a harbor, is that it gives both the adjacent states or countries an aid to industrial development, whereas another line in such a region might turn the advantage to only one, especially if harbors were few in the vicinity.

HIGHLAND BOUNDARIES.

Divide Boundaries.—In New England, for over eighty years, a boundary determined by a divide was the cause of disputes. Historically, this line was first described by a proclamation issued by Great Britain, in 1763, following the Peace of Paris of that year. The line was to cross the St. Lawrence and Lake Champlain in the 45th degree of north latitude, "and thence to proceed along the highlands which divide the rivers that empty themselves into the St. Lawrence from those which fall into the sea."[13]

This precedent led Great Britain, in the treaty of 1782, in describing the limits of the United States, to declare this part of the boundary to be "From the northwest angle of Nova Scotia . . . along the highlands which divide those rivers that empty themselves into the river St. Lawrence from those which fall into the Atlantic Ocean, to the northwestern-most head of Connecticut River. . . ."

It will be observed from the map (Fig. 1) that there is a main

[12] *Ibid*, p. 24.

[13] Daniel Webster, Works, Vol. II, p. 147.

divide and a subdivide in this section of the country. One truly divides all the rivers flowing into the Atlantic from those emptying into the St. Lawrence; the other separates the basins of the St. Croix, Penobscot, Kennebec, etc., from those of St. John, Chaudiere, St. Francis, Yamaska, etc. But the St. John is an Atlantic river and so ought not to be grouped with the St. Lawrence rivers. However, Great Britain reasoned that as in the treaty the St. Lawrence bay was not considered a part of the Atlantic ocean, so the Bay of Fundy, into which the St. John empties, should not be so considered. Hence the St. John is not an Atlantic flowing river. So the highlands to the south were those referred to according to the contention of Great Britain. She was so persistent in this view, apparently for strategic reasons, that compromise finally resulted, concerning which, Webster, who represented the United States, declared the underlying principle to be "that the arrangement shall be for the mutual convenience and advantage of both parties, if the terms can be made fair, and equal, and honorable to both."[14]

As a result the divide boundary was cut down to one fourth the length it would have had, had the "American line" been adopted. As it is today, the boundary extends from the source of the southwest branch of the St. John's "in the highlands at the Metjarmette portage; thence down along the said highlands which divide the waters which empty themselves into the river St. Lawrence, from those which fall into the Atlantic Ocean, to the head of Hall's stream"[15] (25).

The geographic lesson taught by such an outcome seems to be that in a little known country even a divide boundary designated with careful specifications, can be brought into dispute, if the incentive is great enough.

As has been stated above, the line which forms the western boundary of Connecticut, Massachusetts and a portion of Vermont, (14-15-16), practically follows a divide which is nearly at the crest of the Taconic Mountains. Along the southern course, it is the divide between the Hudson basin and that of the Housatonic; and in the northern part, it is a subdivide between the Hudson and its tributaries, especially the Hoosic. But since this boundary was not defined as a divide boundary, it will not be considered here as such.

Crest Boundary.—A crest boundary may be defined as one that follows the highest parts or summits of a range of hills or mountains. It does not necessarily coincide with the divide, for any considerable distance, and may not even approximate it. Land forms are so variant

[14] *Ibid*, p. 151.

[15] Henry Gannett, Boundaries of the United States (3d Edition), *Bull.* 226, *U. S. Geol. Surv.*, p. 17.

in degree of resistance that some rivers, by headward erosion, or otherwise, may have carved their valleys far beyond the general crest line, while others are just approaching it. So the crest line is often very discontinuous. Such is the relation between the divide and crest line in the Andes, where is located the disputed Argentina-Chile boundary; also, in the northward extension of the Rockies, where the Alaska-Canada line was first described as following the summit of the mountains situated parallel with the coast.

As far as specific reference to a crest line goes, New England furnishes no example in her boundaries. But in following a line parallel with and twenty miles east of the Hudson, sections of the eastern New York boundary approximate closely the crest line of the Taconic Mountains, as has already been noticed.

Crest lines, like divides, form lines of separation far from the scenes of people's usual activities, and thus are well adapted to serve as boundaries. But because they are seldom continuous and at best difficult to ascertain, they are less desirable than are divides. Lord Curzon[16] in referring to the Alaska-Canada line, questions "the practicability or meaning of a line that scaled inaccessible peaks and was lost amid ice and eternal snow."

MATHEMATICAL BOUNDARIES.

Parallels.—The shape of the earth is such that lines can be precisely located on its surface in relation to its daily motion. One set of lines so determined are east-west lines or parallels. They are more extensively used as boundary lines in the United States than are any other mathematical lines.

In fact, with the exception of Maine, New Jersey, and Ohio, there is no state in the Union that does not include at least part of one parallel in its boundary. Even in Maine part of the boundary was originally described as a "due east line" but was nullified later; and Ohio, in her constitution, defined the northern boundary as an "east and west line" but that was also made void. One cause for the extensive use of parallels in United States seems to be the comparative ease with which they can be described by diplomats in relation to sections sparsely inhabited, and little known. Another cause that probably had some influence, is the north and south direction of the coast line and the habit of making one set of boundary lines at right angles to the coast line. Still another cause is the early movement of settlement from east to west.

In New England the international representative of this type of boundary is in Vermont (26). In the Treaty of 1842 with Great

[16] Lord Curzon of Kedelston, Frontiers (2d Edition), p. 36.

Britain, this was referred to as "the old boundary surveyed and marked by Valentine and Collins, previously to the year 1774, as the 45th degree of north latitude. . . ." This boundary was first described when England acquired Canada from France in 1763 by the Peace of Paris. It was then that the claim of Massachusetts to the north bank of the St. Lawrence river was disallowed by England and Massachusetts was limited by a line "that was to cross the St. Lawrence and Lake Champlain in the 45th degree of north latitude, and thence to proceed along the highlands. . . ."[17]

In making this change Great Britain was apparently prompted by a desire to bring her newly acquired sections of ethnic homogeneity, (Quebec, New Brunswick and Nova Scotia) into closer physical or geographic union. When the desire was felt, the maps of the region were inadequate to suggest to British diplomats any physical features that might serve the purpose of a boundary, and the region had been little explored. Hence for convenience and exactness the parallel seems to have been adopted.

The greater parts of the northern and southern boundaries of Massachusetts (27 and 28) are described in the original grants, in terms that would seem to mean parallels, and attempts were made to locate them as such, but inadequate geographic knowledge prevented this. In a decision promulgated by the Lords of Trade in March, 1740, the western part of the northern boundary of Massachusetts was described as beginning at a point "three miles due north of Pawtucket Falls, and thence due west to His Majesty's other governments."[18] Thus three fourths of the northern boundary of Massachusetts was defined as the parallel passing through a point three miles due north of Pawtucket Falls on the Merrimac. Richard Hazen attempted to mark this line in 1741, under instruction from Governor Belcher, and allowed for a westerly variation of the needle of 10 degrees. This variation was later found to be too large.

Another error was made in the line, for a constant variation of 10 degrees was used, whereas it should have been constantly decreased from east to west, the total decrease being about one degree. Hence the line curves to the north, favoring Massachusetts. Nevertheless, the line as run was accepted and is still the boundary.

The other Massachusetts boundary that was first interpreted to be a parallel (28-29) was defined in a grant from the council of Plymouth of 1628 in these terms: "all . . . landes . . . lyeing within the space of Three Englishe Myles on the South Parte of the said River called Charles River, or of any or every Parte thereof . . . lyeing within the Lymitts aforesaid, North and South, in Latitude

[17] Daniel Webster, Works, Vol. II, p. 147.
[18] W. Harriman, History of Warner, N. H., p. 561.

and Breadth, and in Length and Longitude . . . from the Atlantic . . . ocean . . . to the South Sea."[19]

Commissioners from Massachusetts and Rhode Island in 1710 discarded the due west line, for some reason not apparent, and adopted one that was to start from a point " 3 English miles distant southward from the southernmost part of the river called Charles River," and run, " so it may (at Connecticut River) be two and one half miles to the southward of a due west line." This brought about a series of controversies over this section of the line (29), that lasted for nearly two hundred years and in which were involved two appeals to the Supreme Court of the United States. Gannett pronounces this prolonged dispute " in some respects the most remarkable boundary case with which this country has had to do."[20]

The reason for this seems geographic. The country over which the line was to run was comparatively level and relatively inviting for settlement, and although distant from the coast line, was much frequented by colonists passing between the Massachusetts Bay settlements and those of Long Island Sound and Narragansett Bay. Thus it was early known and settled, long before an attempt was made to fix the boundary line formally. As early as 1642 a stake was set up on the plain at Wrentham to mark the commencement of the line but the westward extension was not designated. Each colony granted to settlers sections which were presumed to be within its jurisdiction. But since the definition referred the line to no topographic feature, except the point of departure, it could not be ascertained exactly except by skilled geodesists. Thus is illustrated one of the disadvantages of the mathematical line as a boundary. Nevertheless a line of jurisdiction was early established, but this only approximated the defined line of the grant. This gave the colonies, and later the states, many grounds for dispute, and so followed a long controversy. The jurisdictional boundary, a very irregular line, was finally adopted in 1881 and is still extant. It is treated under parallels because its progenitor was a parallel, and a parallel determined its general direction, position, and extent.

The other portion of the parallel which is a part of the southern boundary of Massachusetts, is that separating it from Connecticut (28). This underwent a similar history, and reached a termination similar to the Rhode Island section. As it is today, it is made up of sections of parallels, other mathematical lines (town boundaries), and short topographic lines. It however approximates the parallel originally

[19] Henry Gannett, Boundaries of the United States (3d Edition), *Bull.* 226, *U. S. Geol. Surv.*, p. 54.

[20] *Ibid*, p 55.

described as that of a point three miles south of the southernmost part of the Charles River.

The method of defining a boundary by giving its latitude in degrees as was done with the parallel of 45° in northern Vermont, is very common in the West. Another means, however, has been employed in separating North and South Dakota. The dividing line agreed upon when they were admitted as states was the "seventh standard parallel" from the base of the fifth principal meridian. The "standard parallels" are those which have been carefully laid out by government geodesists in certain parts of the country, as standards for local surveys of boundaries of smaller divisions. "This line is about four miles south of the parallel 40 degrees from the Equator, and was chosen in preference to the geographic parallel because it was the boundary line between farms, sections, townships, and to a considerable extent, counties."[21]

A peculiar method of referring to parallels is found in the Treaty with Great Britain in 1782 in defining the limits of the United States. The line was defined to the Mississippi River, "thence by a line to be drawn along the middle of the said river Mississippi until it shall intersect *the northernmost part of the thirty-first degree of* north latitude."[22] The same method was employed in the Revised Statute of New York of 1881, relative to the southern boundary of that state. The act reads: "then south along said meridian line to a monument *in the beginning of the forty-third degree of north latitude* . . . then east along the line . . . in the same parallel of latitude."[23] The parallel meant here is the forty-second. It was so run and marked.

In both cases the idea of a parallel of latitude seems to be a band about the earth parallel to the equator and one degree wide, with the "begining" nearest the equator.

The advantages and disadvantages of parallels as boundaries are nearly identical with those of other mathematical lines, so they will be numerated later in relation to the larger class.

Meridians.—In the United States among mathematical boundaries, meridians are second only to parallels in extensiveness of use. Meridians as boundaries are illustrated in New England by the northern half of the eastern boundary of Maine (30), and the greater part of the Rhode Island-Connecticut boundary (38).

The Maine line is first referred to in the treaty with Great Britain of 1782 in a description of the northwest angle of Nova Scotia, as

[21] W. E. Johnson Mathematical Geography, p. 234.

[22] Henry Gannett, Boundaries of the United States (3d Edition), *Bull.* 226, *U. S. Geol. Surv.*, p. 9.

[23] *Ibid*, p. 82.

"that angle which is formed by a line drawn *due north* from the source of St. Croix River to the highland." Farther on in defining the eastern boundary of the United States it is said that a line is "to be drawn along the middle of the river St. Croix from its mouth . . . to its source, and from its source directly north to the aforesaid highlands."

It is significant that although prolonged disputes arose concerning the position of the source of the St. Croix, and the highlands that were referred to, there was none over the meridian part of the boundary at any time.

The Rhode Island line is the meridian of the mouth of a tributary. In the charter to Rhode Island, granted by Charles II in 1663, the country was bounded on the west by Pawcatuck river to the head, "and from thence, by a straight lyne drawn due north until it meets with the south lyne of the Massachusetts Colony."[24] Difficulties in locating the main part of the Pawcatuck river, led to a compromise that determined the mouth of Ashawoga river, a tributary, as the starting point of the meridian. In surveying the line the meridian was marked part of the way, but elsewhere, a series of short straight lines forming the jurisdictional boundaries of previous township grants was followed, for those had tried to follow the described line.

In naming meridians as boundaries the more usual custom in the United States is to give their distances from a prime meridian, either that of Greenwich or Washington, instead of the meridians of topographic features as in Maine and Rhode Island. Previous to 1861, Greenwich was the standard for meridians used as boundaries in the United States. At that time, however, in the act that enabled Kansas to become a state, the western boundary was described as "the 25th meridian of longitude west of Washington." Since then Washington has been the standard in such cases. The boundaries of Nebraska, North and South Dakota, Wyoming, Colorado, New Mexico and Utah are examples of this. It seems as if patriotic reasons were responsible for this change.

Thus the eastern boundary of New Mexico is the 103rd meridian west of Greenwich and the western boundary of the same state, the 32nd meridian west of that of Washington. When defined in relation to a standard meridian the task of locating the initial point is more difficult and the possibility of error greater than when the meridian of a topographic feature is the boundary.

In locating a point of the 100th Meridian as the eastern boundary of northern Texas, after using the best instruments obtainable in

[24] *Ibid*, p. 71.

numerous trials, H. S. Pritchett reported a probable error of plus or minus seventy-three feet, and declared that this could not be "appreciably reduced without a redetermination of transatlantic longitudes."[25]

"STRAIGHT LINE" BOUNDARIES.—The "straight line" as used in a boundary definition means the line of intersection between the earth's surface and a plain which contains the termini of the line and the center of the earth, and which unlike a meridian or parallel, does not depend upon the movement of the earth for its direction. Although called "straight" this line is usually very irregular, due to the irregularities of the surface over which it runs. And if the surface were an ideal plain, the line would not be straight because it would be on the surface of a nearly spherical body, the earth. It would really be the arc of a great circle.

After all, the limit of jurisdiction is a plane. The aerial extension may not be commonly conceived until aeroplanes and balloons become much more numerous, but the subterranean extension is of great importance in mining regions. So a boundary is really a plane. It was so acknowledged in a description of a boundary monument to be used on the U. S.-Mexico line as given in a report of the Commissioners. It reads; "These rings will be placed, one at the top of shaft, the others twelve inches below, and will be carefully located *in the plane of the boundary*."

Under this conception the straight line boundary becomes a part of a plane which contains the given termini and the center of the earth. It is the intersection of this plane and the earth's surface nevertheless that monuments mark; so that is the important thing, as far as the present use of the boundary outside of mining regions is concerned.

An example of the "straight line" boundary in New England is the northern portion of the Maine-Quebec line (35), which is a portion of the compromise line between Canada and the United States. In the treaty with Great Britain of 1842, it is described as running from the outlet of Lake Pokenagarnook; "thence southwesterly, in a straight line, to a point on the northwest branch of the river St. John, which point shall be ten miles distant from the main branch of the St. John, in a straight line, and in the nearest direction." In this case drainage features are used to determine the position of the termini, with another straight line as an auxiliary.

The next section of the compromise line to the south is also a straight line (36). From the southern terminus of the line just described, it runs, "in a straight line, in a course about south, eight

[25] M. Baker, The Northwest Boundary of Texas, *Bull.* 194, *U. S. Geol. Surv.*, p. 35.

degrees west, to the point where the parallel of latitude 46 degrees 25 minutes north intersects the southwest branch of the St. John's." Such a reference to a point could be made only in a region that had been carefully mapped and such a point could not be actually located without the aid of skillful geodesists. The line has numerous monuments to show its course.

The longest straight line boundary in New England is the central part of the Connecticut-Long Island line (31). The ratified report of the commissioners in 1880 gave this part as running from the end of a true southeast course three and a quarter statute miles from Byram Point, "thence in a straight line (the arc of a great circle) northeasterly to a point four statute miles due south of New London Light House; . . ."[26] This line is eighty-two statute miles long. With a few short segments of loxodromic curves at either end it determines the respective jurisdictions of New York and Connecticut over the waters and islands of Long Island Sound.

The straight line boundary is illustrated outside New England by portions of the U. S.-Mexico line. California is separated from Lower California by "a straight line drawn from the middle of Rio Gila, where it unites with the Colorado, to a point on the coast of the Pacific Ocean distant one marine league due south of the southwesternmost point of the port of San Diego."[27]

Such a line was used in the Gadsden Purchase of 1853, with short stretches of parallels and meridians. It follows roughly the southern divide the Gila River and so fixes a large part of the United States-Mexico boundary. The reason why the mathematical approximate of this divide should have been used instead of the topographic feature is not clear. The topography is everywhere pronounced making the divide conspicuous. Thus it would have required only a hasty reconnoissance to locate the line and only a few monuments to mark it. As it was, an extended and costly survey had to be made and many monuments erected, some with difficulty and hazard on precipitous slopes.

A rectangular relation is found between the straight line and the divide in the northern part of the Wisconsin-Michigan boundary. A similar relation holds between a straight line and the divide between the Hudson Bay and Gulf drainage in a part of the Minnesota-South Dakota line.

The New York-New Jersey boundary is "a direct or straight line." Before the District of Columbia ceded a portion of its area to Virginia, it was practically a square, bounded by four ten-mile "direct"

[26] Henry Gannett, The Boundaries of the United States (3d Edition), *Bull.* 226, *U. S. Geol. Surv.*, p. 76.

[27] *Ibid.*, p. 24.

lines. The longest "straight line" boundary on the earth is that which constitutes the greater part of the eastern limit of California.

LOXODROME BOUNDARIES.—The loxodrome boundary is a curve that cuts all meridians at the same angle and is oblique to parallels, or it may be defined as a line of constant bearing. It will be observed that this line is unlike the "straight line" in that it cannot be contained in a plane.

In early times, when surveyors had meagre and uncertain knowledge concerning the magnetic variation of the compass, they often allowed for too much or too little variation in fixing boundaries, determined by parallels of latitude. The resulting line was a loxodrome, providing correction was made for the differences of variation in different places. Thus, if the latter provision had been made in running the parallel of northern Massachusetts, since the primary variation was too great, the line would have been a loxodrome. As it is the line is very nearly one.

The mathematical portion of the Maine-New Hampshire boundary (37) is a loxodrome as expressed in the report of a board of commissioners in 1737. From the "furthest head" of the Newhichawack River, the line was to "run north two degrees west till 120 miles were finished . . . or until it meets with His Majesty's other governments."[28] A portion of this line was "spotted and measured" in 1741, a continuance in 1767, and the remainder in 1789.

It was claimed by Massachusetts, with seeming justice, that the first surveyor did not make due allowance for the variation of the compass. It is probable the other two did not correct for annual change in the variation. All three let topographic features influence mildly the position of the line, according to their convenience. So it will be seen the marked line only approximates the loxodrome described in the early papers.

Other examples of the loxodromic boundary in New England, are found in short portions of the Connecticut-New York line in the Sound. Here they are referred to as "a true southeast course" (23), "east three-quarters north, sailing course" (32), etc. Other varieties of expression for the loxodrome are "a line to be run north 45 degrees east" till it intersects a specified river, as in the description of the Virginia-Kentucky boundary; and "from Goat Island northwest to the 35th degree parallel," as in that of the North Carolina-South Carolina line.

The loxodrome is not used nearly so often as a boundary as are the other mathematical lines mentioned above. When it is used in documents the engineers in the field, either through ignorance

[28] New Hampshire Historical Collections, Vol. 2, p. 278.

or for mutual convenience are likely to convert it into a straight line, or a broken line made up of a series of straight lines which approximate the true curve.

ARCS OF SMALL CIRCLES.—This class of mathematical boundaries has no representative in the boundaries of the New England States, but is considered here to round out the class, and because it is an interesting member of the group. As a boundary line a small circle may be defined as a circular arc of small radius, which has for its center a natural or artificial object.

The only state boundary in the Union that includes a circular line is that of Delaware-Pennsylvania. It is described as "an arc of a circle, having for its center the steeple of the old court-house at New Castle, Delaware, and a radius of twelve miles."[29] This circular boundary of a state was evolved from a county line which was described in a conveying deed as "the town of New Castle and a twelve-mile circle around the same."[30] Later Delaware was formed by the union of three counties, one of which was New Castle.

The work of running the line was done years after its definition, and was attended by many surveying difficulties. Such a line in order to be recognized has a unique disadvantage as a boundary, in that it requires an almost continuous visible indication of its course.

The circular boundary is used in the United States very sparingly for town boundaries. Some of the old Hanse towns of Germany were bounded by circular lines.

The study of the mathematical boundaries of New England has shown that, in general, they can be easily expressed in treaties, even in reference to a country that is little known. This explains why they are so common in the United States, Canada, Africa, and Australia. Mathematical boundaries can also be easily identified on a map; they can be definitely located on the ground; and, unlike some river boundaries, their courses can be precisely marked by monuments.

Their one great drawback, and this is vital, is that unless they are carefully related to the topography, they are almost certain to create political divisions in ethnic, physical, industrial, and perhaps religious units, and this may be a basis for strife. Hence the mathematical boundary, especially if it is international, is liable to undergo changes until it becomes more harmonious with the surroundings. This may be one reason why there are so few boundaries of this type in Europe and Asia.

[29] Henry Gannett, Boundaries of the United States (3d Edition), *Bull.* 226, *U. S. Geol. Surv.*, p. 86.

[30] *Ibid*, p. 87.

BOUNDARY MARKS.—Some of the marks by which the courses of the early boundary lines of New England were indicated were indeed crude and inadequate. Yet some of these are still extant as the only authoritative marks. The loxodrome boundary of the Maine-New Hampshire line illustrates the matter. A part of the record reads: "thence same course two hundred twenty-five rods across a bay of said lake; thence same course two hundred six rods across a peninsula of the same; thence same course . . . across the north bay of said lake, to a cedar post marked "N." "M." . . . thence same course one hundred sixty-two rods to a spruce . . . thence . . . to a perpendicular precipice; thence same course . . . to a beaver pond; thence same course . . . to a yellow birch on the highlands."[31]

It will be easily seen how forest fires, clearings by man, and destruction by natural agencies would soon make such a record nearly worthless. It was such a description of a boundary line that made Rufus Choate exclaim, "I would as soon think of setting forth the boundaries between sovereign states as beginning at a blue jay on the bough of a pine tree, thence easterly to a dandelion gone to seed, thence due south to three hundred foxes with firebrands tied between their tails."[32]

EFFECT OF BOUNDARIES ON PEOPLE WHO LIVE NEAR THEM

CONDITIONS NEAR BOUNDARIES.—The effect of a special geographic feature such as a boundary may be clearly seen in the people who live near it, especially if the line is undetermined, ill-defined or disputed. This is well illustrated in the history of the Sound boundary between Connecticut and New York. Before the definite establishment of this line, many of the islands in the Sound were used as convenient resorts by persons wishing to engage in illegal trades or practices, since an arrest under authority of either state might be met by a claim of jurisdiction of the other. The following citations of illegal proceedings in relation to this region are abridged from the New Haven Historical Society Papers, Vol. III.

On one occasion, a party of prize fighters and spectators from New York landed on one of the questionable islands to have an encounter. A company of Connecticut militia was levied, rushed to the scene of combat, and captured the whole party. The counsel of the prize fighters took exception to the jurisdiction of the Connecticut courts on the ground that the acts complained of were committed in New York, and the cases were never brought to trial.

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[31] *Ibid*, p. 43.

[32] W. Harriman, History of Warner, N. H., p. 553.

A case of piracy occurred on a schooner lying a distance from shore in the Sound. The offender was seized, tried and convicted, but the Supreme Court of the United States arrested the sentence of death, because it was doubtful whether the spot where the schooner lay, was or was not within the jurisdiction of New York. A second trial resulted in the pirate's discharge, because the jury were of the opinion that the act was done outside the jurisdiction of the court which tried him.

Thefts and assaults occurred on the many steamers and other crafts plying the Sound, and it was always questionable in what jurisdiction they were to be deemed committed,

The notorious pirate, Captain Kidd, used a small group of the Sound Islands as his haunt because of their inviting position in relation to the unsettled boundary.

Previous to 1853 the boundaries of Massachusetts included a small district in the southwestern corner, called Boston Corner, that was separated by rugged highlands from the rest of the state. For obvious reasons, this became a resort for desperadoes. This condition finally brought about its transfer to the neighboring state of New York.

The more usual activities of people near boundary lines, take the form of evasion of taxes and license laws, illegal voting, and the like. To facilitate the evasion of laws hotels are often built along the line. Experience with this condition led the United States commissioners of the U. S.-Mexico Boundary Commission to recommend that a reservation of not less than fifty feet be declared by the United States to extend along the entire length of the boundary on the American side, and that the Republic of Mexico be asked to declare a like reservation on the Mexican side, and that the erection of buildings on either side, within these limits be prohibited.

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THE INFLUENCE OF LAKE MICHIGAN UPON ITS OPPOSITE SHORES, WITH COMMENTS ON THE DECLINING USE OF THE LAKE AS A WATERWAY

RAY HUGHES WHITBECK

CONTENTS

INTRODUCTION.—Lake Michigan, three hundred miles in length and nearly one hundred miles wide, projecting into the very heart of a rich territory, has notably influenced the location of cities and industries, the direction of railways, and the distribution of population and wealth on the west side; and it has made the east shore one of the summer play grounds of the Middle West, and one of the important fruit belts of the nation.

CLIMATIC CONTRASTS.—Lake Michigan influences air temperatures—especially the maximum and minimum temperatures—for some twenty miles inland from its eastern shore. The heat stored up in summer in the waters of Lake Michigan is given off in autumn and early winter to the prevailing westerly winds and is carried over western Michigan. During the spring the water warms much more slowly than the land; the winds blowing across the lake are cooled and give the shore lands of Michigan a lower temperature than would prevail were the lake not present. This retards the spring, prevents vegetation from responding too promptly to the early warmth, and largely explains the high development of fruit growing on the Michigan side of the lake.

The rainfall on the Michigan side differs little in quantity from that on the Wisconsin side, but the amount of snowfall and the character of the storms are considerably modified. Lansing in the interior of Michigan has, on an average, forty-two thunder storms per year, while Grand Haven on the Lake Michigan shore averages but twenty-six.[1]

[1] Seeley, D. A., The Climate of Michigan and Its Relation to Agriculture, in Rept. Michigan Board of Agriculture, 1917, p. 694.

The shore counties receive from ten to twenty inches more snowfall than the interior counties, and considerably more than the Wisconsin shore counties receive. The effect of the diminished number of thunder storms on the Michigan shore of the lake is mainly of importance as it favors the numerous summer resorts of this region.

The Michigan shore has a higher percentage of sunshine in summer and a higher percentage of cloudiness in winter than the Wisconsin shore opposite.[2] Both the summer sunshine and the winter cloudiness are favorable to fruit growing. One cause of the winter-killing of fruit trees is the desiccation of the wood of the tree leading to the impairment of its strength, and often to its death. If the winters are moist, resulting from a high degree of cloudiness, the injurious desiccation of the wood is prevented, and winter-killing is greatly reduced. It is believed that this is one of the important climatic differences which make fruit growing on the Michigan side far more prosperous than on the Wisconsin side of the lake.

Grand Haven in Michigan lies directly opposite Milwaukee. Its mean January temperature is four degrees warmer than that of Milwaukee, and six degrees warmer than that of interior cities of Wisconsin and Iowa in the same latitude. The January minimum is ten degrees higher at Grand Haven than at points in the interior of Wisconsin and Iowa in the same latitude.[3] The January isotherms of 15° and 20° are bent northward over 400 miles by the influence of the lake. The extremely low winter temperatures which visit Wisconsin are never so severe on the Michigan shore; when it is twenty-five below zero at Milwaukee and thirty below in Madison, it may be only fifteen to eighteen below in Grand Haven.[4]

A corresponding influence of the lake is seen in the summer temperatures. The east shore of Lake Michigan is six to ten degrees cooler during hot waves in summer than is the interior of Michigan. During one of the hottest months on record, July of 1916, the official temperature in the interior of Michigan reached 106°, while along the Lake Michigan shore it was from five to ten degrees cooler (Fig 1). This is another of the reasons for the development of summer resorts on this shore.

The influence of the lake in the northern part of the southern peninsula of Michigan is unusually great. The shore counties have a growing season of one hundred and sixty days as far north as Manistee,

[2] "In January, the actual sunshine in western Michigan is less than 20 per cent of the possible amount." Seeley, *ibid*, p. 697. The *Monthly Weather Rev.*, Jan., 1920, p. 16, gives average for Jan. 1905-12 at Grand Haven as 24 per cent, and Milwaukee, directly across the lake, as 44 per cent.

[3] Seeley, *ibid*, p. 692.

[4] Seeley, *ibid*, p. 693.

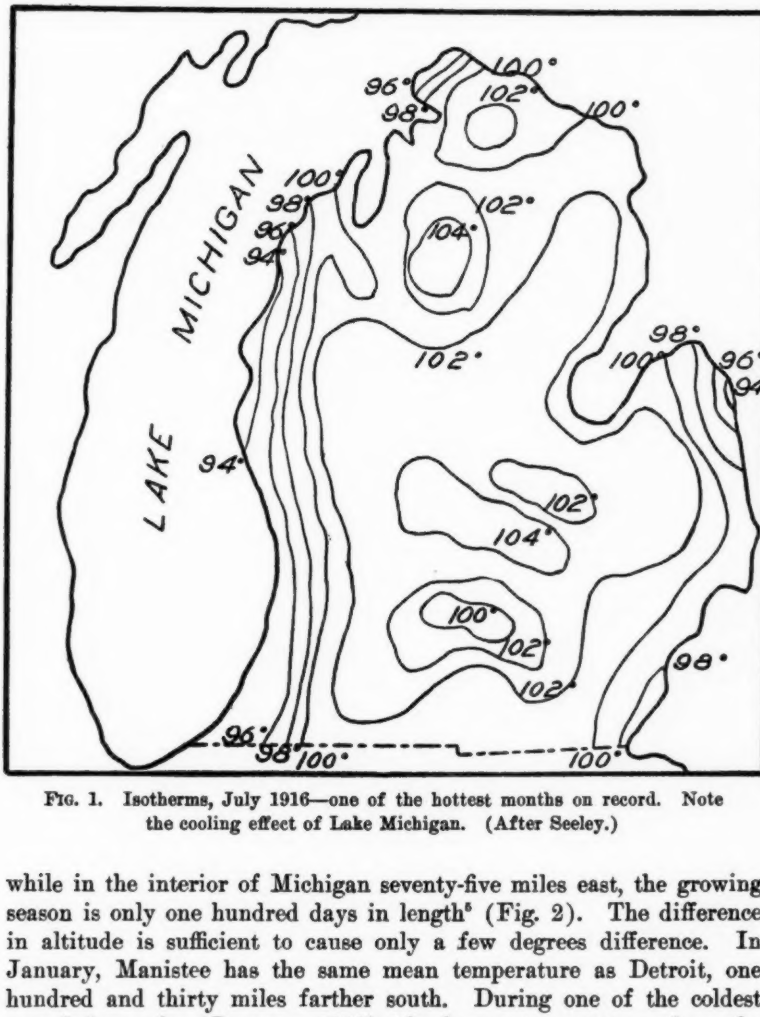

FIG. 1. Isotherms, July 1916—one of the hottest months on record. Note the cooling effect of Lake Michigan. (After Seeley.)

while in the interior of Michigan seventy-five miles east, the growing season is only one hundred days in length[5] (Fig. 2). The difference in altitude is sufficient to cause only a few degrees difference. In January, Manistee has the same mean temperature as Detroit, one hundred and thirty miles farther south. During one of the coldest recorded months (January, 1912), the lowest temperature along the entire Lake Michigan shore of Michigan was —10° F.; while the counties of the southern interior had —20°, and those of the northern interior—35°.[6] It is evident that the effect of Lake Michigan upon the climate of the Michigan shore is marked (Fig. 3).

[5] Seeley's map, Chart XIII, p. 705, shows a small area where the average growing season is only 90 days long. The Atlas of American Agr., Part II, Sect. I, p. 12, shows this region to have a growing season of 90 days in four-fifths of the years.

[6] Seeley, *ibid*, p. 692.

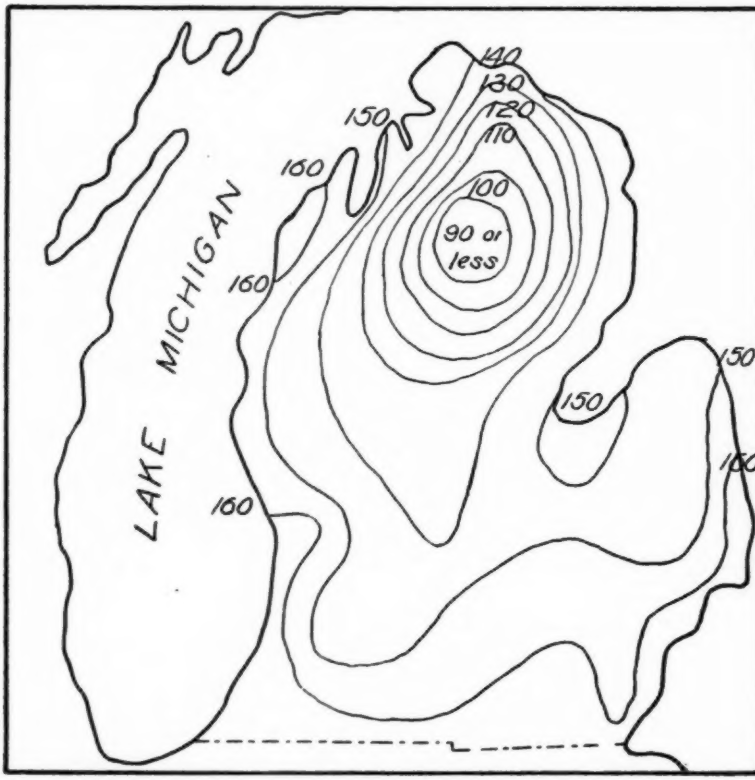

Fig. 2. Length of the growing season in days for Lower Michigan. (After Seeley.)

Fruit Growing.—The accompanying map showing the number of orchard trees in the counties bordering on Lake Michigan in Wisconsin and in Michigan brings out the lake influence impressively (Fig. 4). The Lake Michigan shore counties of Michigan make up one of the important fruit belts of the United States, while fruit growing on the Wisconsin side is only an incident. For example, Van Buren County in Michigan has 550,000 orchard trees, Oceana 600,000, Allegan 800,000, and Berrien nearly 1,000,000; while the highest number of orchard trees in any shore county in Wisconsin is in Sheboygan, 130,000. Berrien County, Mich., produces 50,000,000 pounds of grapes in a good year, while no county on the Wisconsin side of the lake produces even 30,000 pounds. A single county on the Michigan side produces 8,000,000 quarts of small fruits a year, while the highest production on the Wisconsin side is less than one-sixteenth

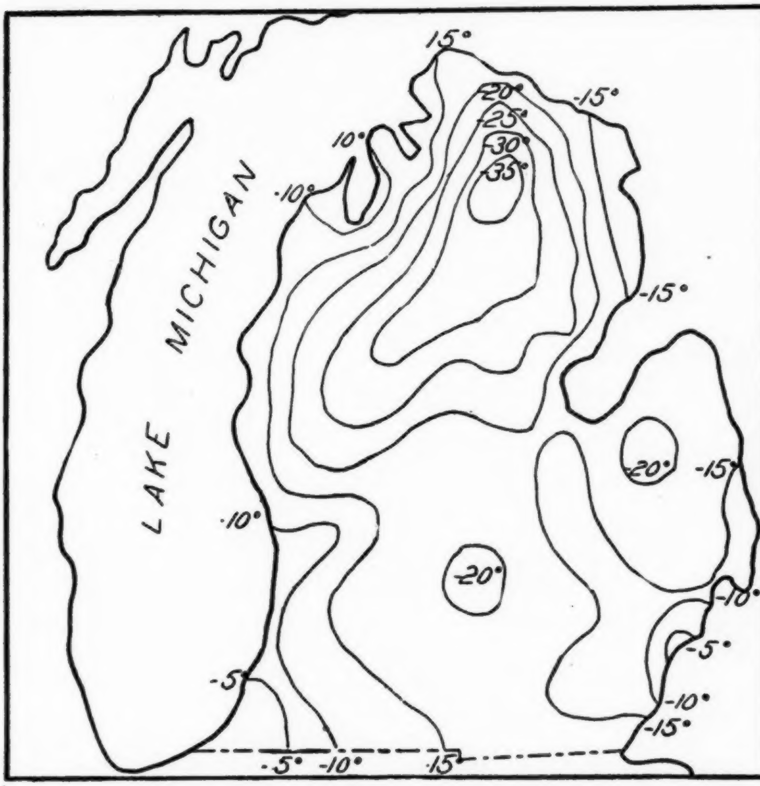

FIG. 3. Isotherms for January, 1912—one of the coldest months on record in Lower Michigan. (After Seeley.)

as much. The most striking difference is seen in peach growing. This has not maintained its former importance in Michigan; yet in 1910 many counties of Michigan produced from 100,000 to 200,000 bushels of peaches, while all the counties on the Wisconsin shore produced only a few hundred bushels.[7] In short, peach growing has been an important industry in Michigan, while just across the lake in Wisconsin it has never attained even incidental importance.

SUMMER RESORTS.—There are at least 40 cities and towns along the Michigan shore of the lake in which summer hotels and a general development of summer resort activities have attained prominence. Several towns on the Michigan side have from five thousand to ten

[7] Data from U. S. Census of 1910.

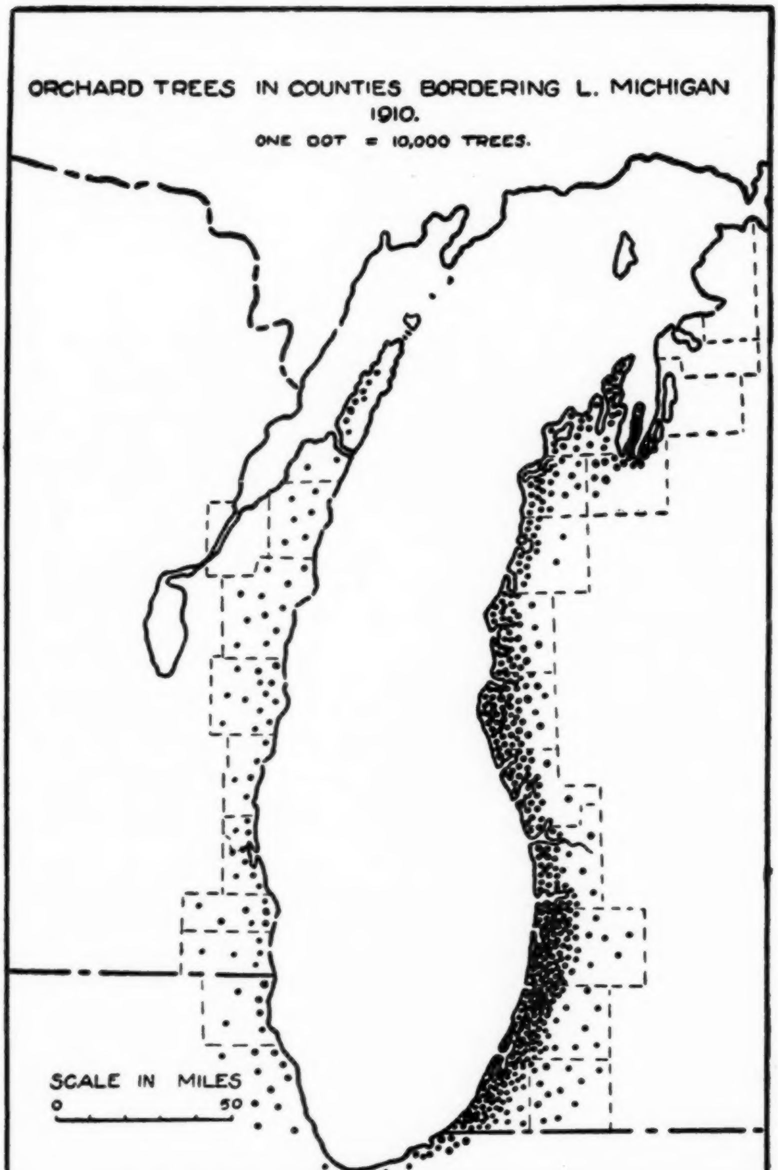

FIG. 4. Relative importance of fruit growing on the opposite sides of Lake Michigan.

thousand additional summer residents, and some of these towns entertain from fifty thousand to one hundred thousand transient visitors during the summer. Figure 5 shows the number of passengers taken by steamers in 1914 to various cities along the shore of Lake Michigan. On the Wisconsin side the only city receiving any considerable number of passengers by lake boat was Milwaukee and very few of these were summer tourists. The prevailing westerly winds, blowing across the lake, cool the Michigan shore in summer from five to ten degrees, and this is sufficient to give Michigan its advantage over the Wisconsin shore of the lake in attracting summer visitors.

Population and Industry.—Between 1840 and 1860, when home seekers were pouring into the Middle West, the Great Lakes formed one of the chief routes of westward movement. The settlers could land at points on Lake Michigan either in Michigan or in Wisconsin. The two sides of the lake had equal opportunities for securing settlers. Both sides of the lake have had an equal length of time in which to acquire population and develop industries; yet the Wisconsin shore counties have attained three times the population and a far greater industrial development. This has resulted in a much greater accumulation of wealth here than on the Michigan side. The barricade of sand dunes along the Michigan shore (due to the prevailing direction of the wind) was not an attraction to home seekers. In these comparisons no account is taken of Chicago, which is, to all intents and purposes, at the southern end of Lake Michigan, and is therefore disregarded in comparing the eastern and western shores of the lake.

Of the largest ten cities in Michigan only one is on the shore of Lake Michigan, and this one, Muskegon, is the smallest of the ten. Of Wisconsin's largest ten cities, five are on Lake Michigan and one of these has a larger population than all of the cities and towns in Michigan on the Lake Michigan shore (Fig. 6). In Wisconsin the most marked concentration of population and industries is along the shore of Lake Michigan, while no such concentration exists on the opposite side of the lake.

Influence of Lake Michigan and the Mississippi River Contrasted.—The influence of the Lake Michigan waterway upon Wisconsin may be contrasted with the influence of the Mississippi River, on its western boundary. In 1910 (the last published census), the average valuation of all property per square mile in the counties adjacent to the Mississippi River was about $47,000, while the average valuation per square mile of the lake shore counties was nearly $200,000, or four times as much. For the counties south of Door County the

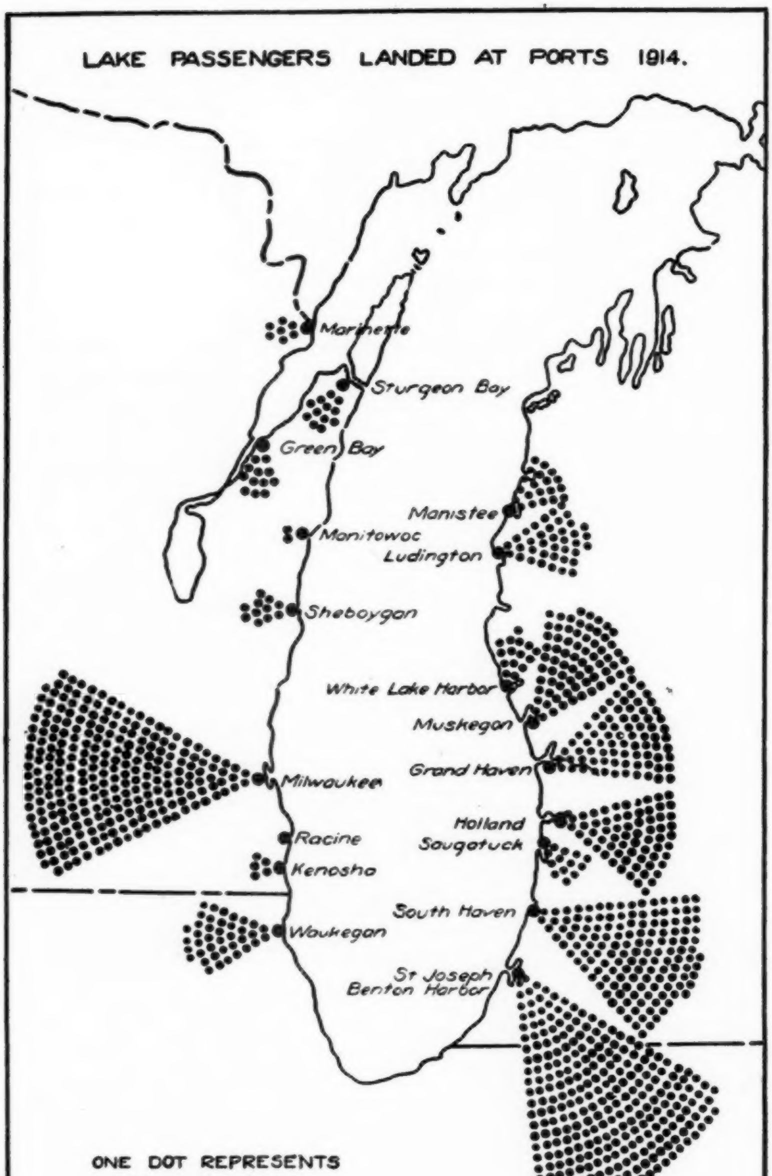

FIG. 5. Passengers landed at Michigan ports—mostly tourists, except at Milwaukee.

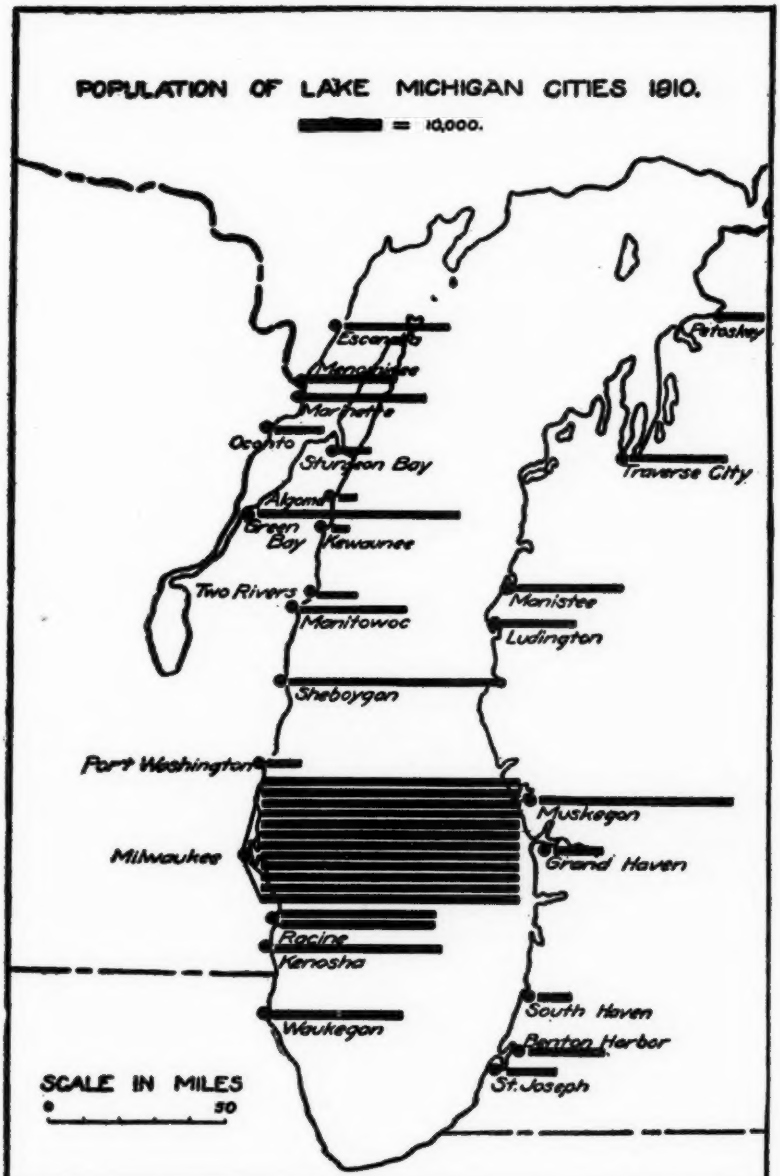

FIG. 6. Population of Lake cities in Michigan and Wisconsin.

average valuation rises to over $400,000 per square mile, and in the three southernmost lake shore counties, the valuation rises to $1,000,000 per square mile.[8]

Lake Commerce.—The chief movement of products from both Wisconsin and Michigan is toward the east. The water gates through which the products of Wisconsin pass eastward are those of Lake Michigan, while in Michigan they are those on the eastern side of the state; hence the lake ports of western Michigan have practically no hinterland. Incoming lake traffic enters Michigan from the east and Wisconsin from the east. This has given a large importance to the Wisconsin ports on Lake Michigan but practically no importance to those of Michigan. This idea is emphasized by the drawing showing the freight movements in and out of Lake Michigan ports (Fig. 7). Aside from Ludington and Grand Haven, there is practically no freight movement in or out of the ports on the east shore of the lake. These two cities are the termini of car ferries from Kewaunee, Manitowoc, and Milwaukee, and the freight movements to these ports are almost entirely through-freight destined to eastern markets. With the exception of the car ferry traffic the freight movements in and out of the Michigan harbors of Lake Michigan are negligible, while those on the Wisconsin side rise to millions of tons annually; yet as will appear later, the relative importance of traffic on Lake Michigan, except in coal and grain, is declining.

Development of Manufacturing.—Half of all the manufacturing done in Wisconsin is done in six cities on the shore of Lake Michigan. Aside from lumber and salt there has been very little manufacturing on the Michigan side of the lake. Not one city, excepting Muskegon, can be called a manufacturing city, while Kenosha, Racine, Milwaukee, Manitowoc, Sheboygan, and Green Bay in Wisconson are all distinctly manufacturing centers deriving most of their advantage of location in the past, at least, from their position on the lake.

The Declining Importance of Lake Traffic on Lake Michigan.—During the first half century of statehood, the importance of Lake Michigan to the industries of Wisconsin was very great but that influence has diminished relatively during the past twenty years, and has declined absolutely during the last ten years. The Wisconsin cities on the lake shore owe their start and their industrial momentum to the lake, but these same cities have grown most rapidly during the past two decades and during these decades lake transportation has declined in relative importance so far

[8] Data from U. S. Census of 1910.

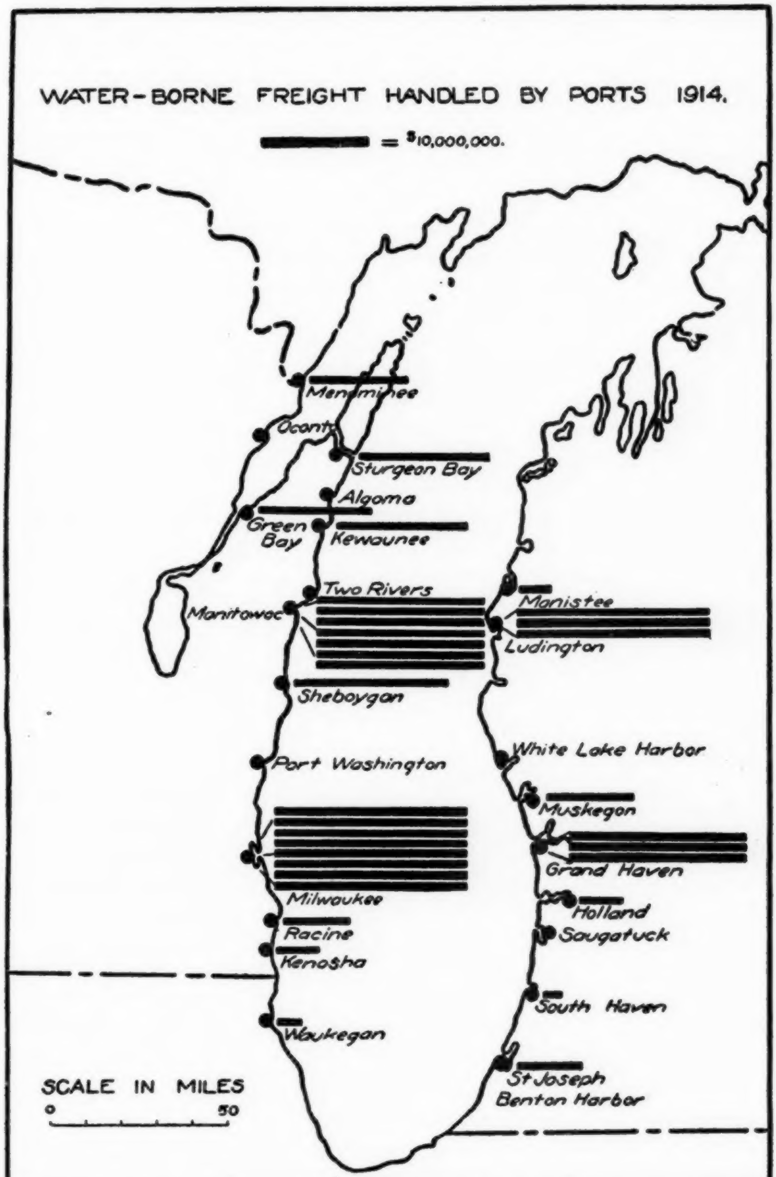

FIG. 7. Contrast of water borne traffic handled by ports in Michigan and Wisconsin.

as Wisconsin is concerned. The only incoming freight of importance is coal, both hard and soft, from Lake Erie ports. If hard coal is to be used in Wisconsin it must come from Pennsylvania, and about $2.00 a ton is saved in freight charges if it comes by lake. Soft coal can be obtained by rail from Indiana and Illinois as cheaply as eastern soft coal can be obtained by rail and lake, and more cheaply in the case of a large part of the state.

Car Ferries.—Car load shipments from the northwest destined for eastern markets can in many cases save time by crossing Lake Michigan on car ferries, thus avoiding the haul around the south end of the lake and also the congestion which often exists at Chicago. Fifty per cent of the lake shipments from Milwaukee and twelve per cent of the receipts by boat use the car ferry. To such shipments the lake is a disadvantage for the ferry is simply a form of bridge by which railroad traffic crosses the lake. This increases the cost of handling freight. Were the lake not here the rail lines would cross the area now occupied by the lake at less cost and greater speed than is now the case. Three car ferries connect Milwaukee with Ludington, Muskegon, Grand Haven, and South Haven; and Manitowoc and Kewaunee, with Ludington and Frankfort.

Increasing Importance of Rail Traffic.—Prior to the Civil War a major part of the general freight received at and shipped from the Lake Michigan cities was carried by lake boats. Regular lines of steamers ran to Lake Erie ports and to other ports on Lake Michigan. Great numbers of passengers and large quantities of freight of all kinds came and went by lake steamers and schooners. Today Milwaukee is the only Lake Michigan port in Wisconsin that receives or ships any considerable amount of commodities except coal by lake. Eighty per cent of the incoming freight at Milwaukee is coal from the East and over fifty per cent of the outgoing freight is grain.[9] Both of these commodities are handled in full cargoes, are loaded and unloaded by special machinery, and are carried long distances, usually 800 miles or more. Under such conditions, lake transportation is cheaper than rail. Yet it is noteworthy that receipts of coal by boat at Milwaukee, Racine, and Kenosha are declining and those by rail are increasing. It is to be noted that whereas iron ore and coal shipped by the lakes average scarely one mill per ton mile, the miscellaneous products shipped short distances (in 1917) averaged over 7c a ton mile, or 70 times as much.

[9] Report of Milwaukee Harbor Commission, 1919, pp. 24, 25.

Manufacturing in these lake shore cities of Wisconsin has increased very rapidly in recent years, but the increased business is practically all being handled by the railroads. So far as these cities are concerned very little freight is handled either by boat lines connecting with the lower lakes or by along-shore lines. For example, only four per cent of Milwaukee's tonnage of lake freight is carried by along-shore steamship lines, and only three per cent by regular lower lake lines.[10] The along-shore traffic is almost wholly package freight carried by three or four steamers which ply between Milwaukee and Chicago, one line calling at Racine and one at Kenosha. These along-shore steamers impose practically the same freight charges as do the railroads, but merchants or manufacturers in Milwaukee or Racine can order articles from Chicago and get them more promptly by boat than by rail. The saving is in time rather than in cost.

Milwaukee, Racine, and Kenosha receive large quantities of material and ship great quantities of manufactured goods; yet very little of either goes or comes by lake. A few specific examples may serve to illustrate how little use manufacturers are now making of lake transportation. The largest manufacturing concern in Racine is the J. I. Case Threshing Machine Company, makers of threshing machines, tractors, automobiles, and farm machinery. Their main plant is on the harbor of Racine and their new South Plant is on the lake shore; yet during the past summer the company was making no use of the lake for transportation. Even the coal came by rail; and the steel, which is made by the Illinois Steel Company of Milwaukee, also on the lake shore, came by rail. At present nothing is shipped away by boat. Moreover, the Illinois Steel Company of Milwaukee gets most of its pig iron and steel billets from Gary, which is also on Lake Michigan; yet even these heavy commodities are shipped by rail.

One of the largest concerns in Kenosha, the Simmons Manufacturing Co., owns a large part of the water frontage of Kenosha harbor, having its own docks; yet it receives none of its coal or raw materials by lake and ships all of its products, amounting to 8,000 cars a year, by rail.

It is a matter of some surprise that, though the United States government has expended nearly as much money on Racine and Kenosha harbors from 1910-1916 as in all previous years combined, yet the lake traffic (except coal) has declined to a negligible amount and even coal receipts are declining.

It is disconcerting to find that a great natural waterway like Lake Michigan, with such large cities as Chicago and Milwaukee and several smaller but rapidly growing cities on its shore, seems to be actually declining in usefulness. The traffic in and out of Milwaukee harbor is

[10] *Ibid*, p. 23

less than it was ten years ago and that in and out of Chicago harbor is less than half what it was in 1905, although the tonnage—chiefly iron ore—entering South Chicago harbor has increased. At the same time the rail traffic parallel to the shore of Lake Michigan has increased with great rapidity. Three double track steam lines, one single track steam line and an electric line, or eight tracks in all, connect Milwaukee and Chicago. On these lines there is a constant succession of trains; yet one may sit on the shore of the lake all day and see only occasionally the smoke of a passing steamship. A resident of Racine told me of taking a trip by boat from Kenosha to Racine in the early eighties and counting 60 lake boats in traveling this distance of ten or twelve miles. Another man told of seeing 80 lake boats tied up for the winter in Racine harbor. Not one-tenth as many would now be seen, though the boats in use at present are larger than those used in the past.

The improvement of waterways, often urged as a means of relieving congestion on railroads, seems of questionable aid in case of waterways that are closed by ice all winter when congestion most often occurs. During the late war when transportation lines were strained as never before, the Great Lakes were used slightly, but only slightly, more than in normal times and availed little, if at all, in relieving rail congestion, and the same has been true since the war. Owing to the sale of lake steamers to foreign buyers in the first years of the war, our lake fleet was reduced and service was already curtailed when we entered the war and most needed it. Owners of lake boats have no hesitation in discontinuing service whenever it is to their interest to do so. In recent years there has been a constant decline in this service along the Wisconsin shore of Lake Michigan. Shippers can not count on permanence of freight service by lake boats, for the boat owner will sell his boat or transfer it to another route if he chooses. Railroads give a far better guarantee of regular and permanent service, and rates are controlled by state or government commissions. Railroads operate the year round and railroad spurs may be built to the very doors of the factory. One is led to ask, if water traffic on a great natural waterway like Lake Michigan is not able to maintain itself except in a few special commodities, what must happen to traffic on rivers and canals?

Conclusion.—The influence of Lake Michigan upon its two shores has been very different indeed. On the Michigan side it is mainly a matter of climate, resulting in a high development of fruit growing and of summer resorts. On the Wisconsin side neither of these developments has taken place, but the lake has induced a very marked concentration of population, wealth, industry, and commerce. There has been little development of urban centers on the Michigan side, but a very notable development in Wisconsin. None of the cities on the east

side of the lake are railroad termini of importance. All of Wisconsin's important railroad termini are on Lake Michigan, and all but one of its more important early railroads were built inland from points on the lake. The high point of Lake Michigan's influence in the industrial development of Wisconsin was in the past. To this there is one marked exception; that is the advantage to the lake shore cities in securing coal from the East. In short, Lake Michigan has been only a minor factor in the industrial life of Michigan, but it has been in the past a very large influence in that of Wisconsin. However, when the present is considered, water transportation seems to have very little to do with the great industrial development which is taking place in the Wisconsin cities on Lake Michigan. Even the receipts of coal by lake are declining, while the great quantities of heavy material passing between Gary, Chicago, Milwaukee, Racine, and Kenosha, are practically all carried by rail, and this in spite of the fact that many of the largest manufacturing plants that ship or receive these heavy commodities are themselves on the water front. The cause seems to lie in the fact that railroad service is usually more dependable, and more convenient, operates twelve months in the year, and costs little if any more, except in the case of cargo shipments of bulk commodities carried long distances, as is the case with iron ore, coal and grain.

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WEATHER CONDITIONS AND THERMAL BELTS IN THE NORTH CAROLINA MOUNTAIN REGION AND THEIR RELATION TO FRUIT GROWING

HENRY J. COX

CONTENTS

INTRODUCTION.—A research of the thermal conditions in the North Carolina Mountain region was inaugurated in 1912 by the speaker, in behalf of the United States Weather Bureau, and at the request of the North Carolina State Board of Agriculture and the State Horticulturist, with a hope that the so-called Thermal Belts might be more clearly defined, and that safe elevations for the planting of fruit trees might be determined, as far as possible, in the various sections.

Considerable success had been attained in many portions of that region in the growing of hardy fruit, especially apples, but here and there marked failures had occurred, supposedly because of either too great altitude or unfavorable topography, inducing freezes in the one case and severe frosts in the other.

Heretofore, the planting of orchards in the mountain region had been carried on in a rather haphazard way, so far as the influence of temperature conditions was concerned, and it was believed by the State Horticulturist that an exhaustive study of the various problems might furnish valuable information for the guidance of orchardists in the development of their properties.

Reference has frequently been made in meteorological and climatological literature to thermal belts or frostless zones in mountain districts, both in this country and in Europe. These belts of varying width in which frost is never observed were said to be found on certain slopes between the valley floor and the summit, their development being due mainly to the fact that during certain cool nights the temperature is relatively high on the slope—much higher than at the base.

This phenomenon, termed an inversion of temperature, is observed most frequently on clear quiet nights, but sometimes on partly cloudy

and even cloudy nights. It is called an "inversion" because ordinarily we expect a lapse in temperature with elevation, which, for the want of a better name, we may here term a "reversion," in contrast with the term "inversion." On the average, the temperature of the free air falls with height, the mean rate of decrease being 1° F. in 300 feet of ascent; and there are many nights in the mountain region when this decrease in temperature with elevation is observed, sometimes greater even than the average rate, especially when the weather is cloudy and windy. There are still other nights, moist and damp, when the differences in temperature between various elevations are hardly appreciable.

Both inversions and reversions are quite pronounced on mountain slopes of considerable vertical height and are important factors in the question of fruit-growing. In the one case the minimum temperature is lowest at the base and highest at some point on the slope or at the summit, while in the other case the minimum is lowest at the summit and highest at the base; and, through a combination of these two conditions, we sometimes have a belt more or less indefinite in width where the minima average higher than at either the base or the summit, free from the frosts of the valley and from the freezes of the higher levels. Within this belt, which has been called a "verdant zone," the foliage is frequently fresh and green as compared with that above and below.

Description of Region.—More has probably been written regarding thermal belts in the North Carolina mountains than in any other section of the country, doubtless because the phenomena are more pronounced there than elsewhere in the east, on account of the more extensive slopes and the greater area.

The Appalachian Mountains, which form the divide between the great central valleys of the United States and the Atlantic Plain, extend in a southwest direction from Pennsylvania to northwest Georgia, but the culminating section of the system lies in western North Carolina. While the elevation of the Atlantic Plain at the base of the mountains is only 150 feet in Pennsylvania, and perhaps 500 feet in Virginia, in North Carolina it rises to about 1,000 feet.

The Appalachians divide into two chains in Virginia, one, known as the Great Smokies, continuing in its southwesterly course and forming the boundary of western North Carolina; and the other, retaining the name of the Blue Ridge, as the range in the north is called, crossing the state farther eastward and forming the great watershed of the drainage of that section. Between the two chains lies a remarkable region of valleys and plateaus, at no point falling to a lower elevation than 2,000 feet, while portions of the plateau in Watauga County to

the north and Macon County to the south have an elevation as high as 4,000 feet. Within this system, scores of mountain peaks rise to an altitude of more than 5,000 feet, and many even more than 6,000 feet, Mt. Mitchell being the highest with an elevation of 6,711 feet.

The North Carolina mountain region, then, is preeminently a land of high mountains and plateaus; and because of its elevation, it is known as the "Land of the Sky," a region most irregular in shape, having an area of over 5,000 square miles, and extending in a northeast and southwest direction about 125 miles.

In a general view, the eastern chain, or Blue Ridge, is seen to be irregular and fragmentary, while the western chain, the Great Smokies, is more regular, elevated, and continuous. Nevertheless, the drainage of the plateau between the two is thrown entirely to the westward. Numerous cross chains uniting the main ranges form basins which contain the mountain tributaries of the Tennessee River. Projecting into the Piedmont region east of the Blue Ridge are a few detached chains and isolated knobs.

The principal streams of the mountain region rise in the Blue Ridge, and these flowing westward break through the more elevated western barrier in deep chasms, the French Broad, the North Toe, and the Pigeon, all flowing into the Tennessee; and the Tuckasegee, into the Little Tennessee; while those on the other side of the ridge flowing eastward are the Yadkin, emptying into the Pee Dee River, and the Catawba, separated from the Yadkin by the Brushy Mountains and flowing first easterly and then southerly through the Piedmont region into the Atlantic.

The mountains are for the most part covered with timber up to their very summits, even Mt. Mitchell having considerable forest growth at the highest point; but there are a few peaks termed "Balds" with elevations of 5,000 feet or more whose rounded knobs are almost bare of timber.

General Temperature and Rainfall Conditions in Region as Affected by Elevation.—The modifying effect of elevation on the general meteorological conditions of the region is two-fold:—a reduction in temperature and an increase in rainfall. The isotherms as they approach from the eastern lowlands curve southward rapidly and, after crossing the mountains more or less irregularly at right angles, bend sharply northward; while the rainfall is much greater in the mountain region than at the lower levels, and is greatest over the more elevated sections, especially those on the side of the mountains facing the rain-bearing winds.

Taking temperature conditions in the sections to the east of the mountains as a basis, there is normally, because of the difference in

latitude, about 2° difference in the mean annual temperature between the northern and southern limits of this mountain region. In the lower levels the isotherm of 59° runs somewhat south of the Virginia-North Carolina border, while that of 61° is approximately in line with the Georgia-North Carolina boundary. Temperature data for the summits of the highest mountains are not available, but the means deduced from the observations at places having altitudes up to 4,000 feet are sufficient to show strikingly the effect of elevation upon temperature. The lowest computed annual mean for a considerable period in the mountain region is 49°, observed at Blowing Rock and Highlands, both about 3,600 feet above sea level, one place being in the extreme northwestern portion and the other in the extreme southwestern portion of the state. Because of the difference in latitude, Blowing Rock should normally average 2° colder than Highlands, but this variation is not apparent in the observations because of difference in topography, the station at the latter place being located in a well marked frost pocket, where the night temperature averages uniformly low. This mean annual temperature of 49° is approximately the mean of the Weather Bureau station at Albany, N. Y., where the thermometer shelter stands about 100 feet above sea level.

The rainfall in the Carolina mountain region varies considerably and it is generally much heavier than on the Atlantic Plain. The largest amounts occur along the main Blue Ridge, especially on its southern and eastern sides, as the principal rain-bearing winds in that section are from east to south. The southerly winds carry the moisture-laden air from the Gulf of Mexico, and naturally the greatest rainfall is recorded at the stations farthest to the south where these southerly winds, moving northward, are pushed upward over the slopes, the cooling of the air resulting in condensation, often excessive. During a 4-year period, 1913-1916 inclusive, the gage at Highlands registered an average annual precipitation of 97.88 inches, the total in 1915 being 111.21 inches, and in 1916, 105.10 inches, two extremely wet years. In the same period the cooperative station at Rock House, formerly known as Horse Cove, about six miles southeast of Highlands, recorded an average rainfall of 94.62 inches. These figures are considerably above the average for a long period of years, which are respectively 80 and 82 inches, but in any case this spot in the mountain region close to the North Carolina-Georgia boundary is the wettest place in the United States, except the extreme north Pacific coast.

The rainfall over the Great Smokies is much less than along the Blue Ridge, because the southerly and easterly rain-bearing winds are shut off, or at least their moisture is largely condensed over the Blue Ridge before reaching the Smokies. Moreover, the rainfall on

the plateau inclosed by these two mountain ranges is very much less than on the surrounding mountains, obviously because of the condensation of a large portion of the moisture at the higher levels before the winds reach the plateau, Asheville, in the valley of the French Broad River, and walled in by mountains, registers an average annual rainfall of only 39 inches.

Scheme of Work and Distribution of Stations.—Although the special research was inaugurated in 1912, it was not until the first part of 1913 that all the stations selected were in full operation. The observations thereafter continued until the close of 1916. Stations were installed at 16 places in the mountain region, Bryson being the most westerly, Mt. Airy close to the Virginia border, the most northerly and easterly, and Highlands and Tryon, close to the Georgia and South Carolina borders, respectively, the most southerly. At these 16 places there was a total of 66 stations, varying at each place from 3 to 5 in number. The most elevated place is Highlands, with stations ranging in altitude from 3,350 feet to 4,075 feet, and the lowest is Tryon, its base station having an altitude of only 950 feet. Six of the slopes have differences in elevation between base and summit of 1,000 feet or more, the longest slope, 1,760 feet, being at Ellijay. Some of the slopes are steep, and others are gentle, irregular, and broken up into coves and frost pockets. Some are heavily timbered, while others are comparatively free from forest growth, just as certain of the individual stations are surrounded by dense vegetation while others are more or less bare.

At one place, Asheville, the stations are located above a valley floor on two facing slopes, northerly and southerly, while at two other places the stations are on slopes leading down from different sides of knobs. Nearly all the short slopes lead up to isolated knobs. Some of the valleys at the base of the slopes are narrow and confined, and others are comparatively broad; again, some base stations are located on broad benches. A wide range of conditions has thus been afforded for investigation.

The places were fairly well distributed, all being located in the main portion of the mountain district with the exception of Wilkesboro and Mount Airy, which lie in the foothills to the east. Two places, Blowing Rock and Altapass, are on the main Blue Ridge. There was no definite uniformity observed in determining the positions of the stations on the individual slopes, the exact locations in some cases being dependent upon conditions beyond the control of the investigator, the purpose being to place at least one or two stations in each group within an orchard when one was available.

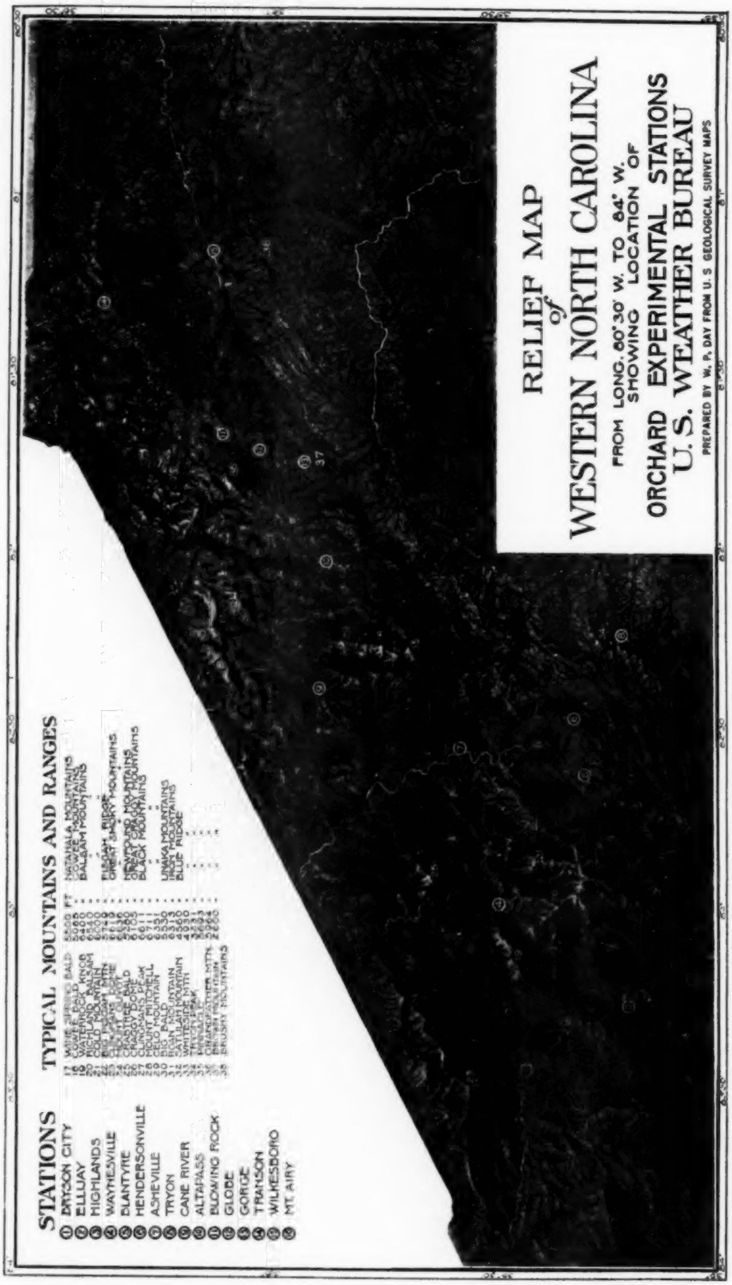

FIG. 1. Relief map showing location of stations.

Minimum Temperature and Causes of Inversion.—During the research a great variety of conditions was studied, including practically all meteorological factors,—maximum temperature and minimum temperature, relative and absolute humidity, rainfall, wind direction and velocity, cloudiness, sunshine, etc. However, in this brief paper the discussion will be confined to that of minimum temperature during both inversion and reversion conditions and its bearing upon the thermal belts and verdant zones.

In the mountain region there is frequently at night a complete reversal of average conditions, so far as minima are concerned. There, after the heat of the day, the entire valley is filled with a sea of comparatively warm air, but as night approaches and the loss of heat is greater than that received from the departing sun, the temperature falls steadily, the change being especially noticeable on the valley floors and the lower levels of the slopes close by where the sunshine is shut off early. On the floor of the valley, the surface air in contact with the soil and vegetal cover rapidly cools and remains stagnant, while the free air above is still warm. Moreover, the surface air in contact with the soil and vegetal cover on the slopes also gradually cools and, naturally, becomes cooler than the free air of the valley at the same levels. As differences in density develop, a convective circulation is established practically horizontally between this free air and the surface air of the slope, the latter as it cools draining slowly down and out over the valley. The free air, itself, loses its heat only slowly by radiation, and at the higher levels it naturally maintains a much higher temperature than the air below which has been cooled by contact with the slopes and valley floor. In this exchange between the warm free air of the valley and the surface air, the air over the slope is prevented from falling to as low a point as it otherwise would, and thus its temperature is higher than at the base. The degree of difference varies and is chiefly dependent upon the amount of free air available for interchange and the opportunities for radiation.

The observations in this region show remarkable temperature variations. The tendency toward inversion is so strong that this condition was observed four times as frequently as the supposed normal distribution of temperature or that of reversion. Moreover, at all places without exception the minimum temperature for the 4-year period, including all kinds of weather, averaged lowest on the valley floor. At Ellijay, where the slope has a vertical height of 1,760 feet above the base, the average minimum at the summit was 3.3° higher than on the valley floor, although, if the average lapse were maintained, the difference would be in the other direction and amount to approximately 6°. On individual nights, on this slope, and even at

the summit, the minimum was often 15° to 20° higher than at the base.

Generally speaking, throughout the mountain region inversions of 20° were frequently noted. The greatest inversion during the entire

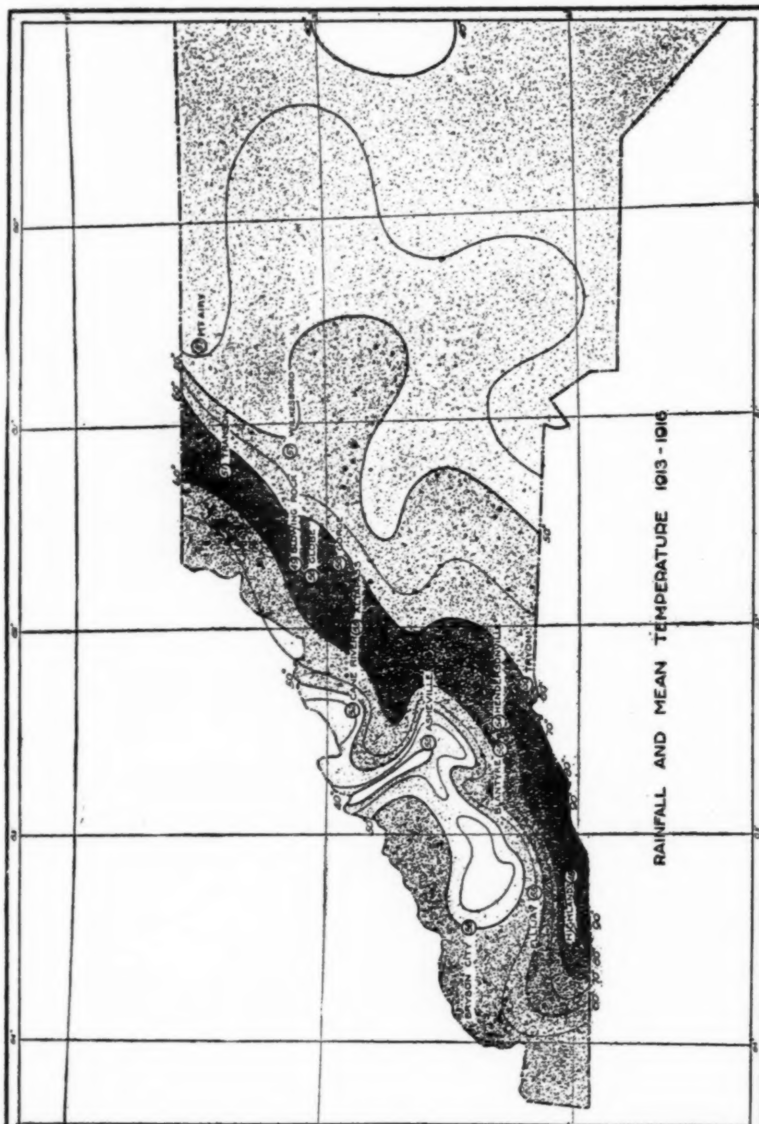

FIG. 2. Shaded areas indicate average annual rainfall and figures in circles the mean temperature.

research was observed on Brown Mountain, November 13, 1913, when the temperature at the summit registered 31° higher than at the base, more than 1,000 feet below.

Inversions have been supposed to be confined practically to anticyclonic conditions—high pressure and clear weather—which may be called the Ideal type. But inversions are also noted in the Carolina mountain region under cyclonic conditions, when as a storm approaches, the temperature rises much more rapidly at the summit than at the base, warm winds at the lower levels being shut off by obstructing mountains, and the cold air in pockets, coves and valleys being at the same time retained. There is even another type between the Anti-Cyclonic and the Cyclonic that might properly be called the Intermediate or Recovery type, although the term "weak-cyclonic" might answer. In this type the temperature is observed to be falling at the base and actually rising at the higher levels.

The highest minimum during inversion conditions was found at varying distances above the valley floors, depending upon the configuration of the surrounding country and the length of the slope. At Ellijay, the longest individual slope, 1,760 feet, the center of the thermal belt was usually at a point about 1,200 or 1,300 feet above the floor, while on all short slopes, less than 1,000 feet and leading up to knobs, the highest minima were observed on the knobs themselves during inversion weather.

The Influence of Topography on Inversion.—The minimum is always low, or comparatively low, at points where there is little, if any, warm free air available for interchange. While this condition is most pronounced on a valley floor, it is also quite evident in a sheltered cove, even though located on a slope. On gradual slopes the minima are lower for the same reason than on steep slopes, a given area on the latter having a much larger amount of free warm air facing it, and at the same time not being so freely exposed to the sky as to suffer the same loss through radiation as the gentle slope. Again, when a slope has opposing mountains close by, thus reducing the amount of air available for interchange, the minima are even lower, though these mountains raise the sky line and thereby tend to reduce the loss of heat through radiation. This is especially noticeable in the lower levels of the gradual slope of Brown Mountain with low hills close by, where a station 250 feet above the base averages almost as cold as that on the valley floor.

Although the summit of a mountain is usually situated ideally for radiation purposes, with a free exposure in all directions, nevertheless, during inversion conditions the highest minimum is noted at the very summit, except when either its surrounding mass is great or

its vertical height is great, a knob partaking largely of the temperature of the free air.

The mass in the region of the summit is a most important factor. Where the mass is great, a large number of radiating surfaces are present which serve to reduce the temperature to a greater degree than if the summit were a mere knob, and in thus lowering the temperature in the vicinity of the summit, the center of the thermal belt is also lowered.

The center of the thermal belt is lowest, then, on a mountain slope where there is no opposing slope nearby and where the mass above in the region of the summit is great. The slope at Tryon is a typical example of this condition, where the highest minimum is usually found at an altitude of less than 500 feet above the valley floor, there often being differences of 15° to 20° between these points separated by only a few hundred feet.

On the other hand, the center of the thermal belt on a slope is high when the opposing slope culminates in a knob so that there is no considerable mass near the summit; and this is so whether there are opposing slopes or not.

When opposing slopes are present in the lower levels and there is a great mass above near the summit, the thermal belt is relatively narrow, as both these conditions tend toward lower night temperatures. Such a slope, as a whole, is cold. If, on the other hand, the slope is steep and there are no opposing slopes and no great mass near the summit, the entire side of the mountain is relatively warm during night inversions, here being present all the conditions that favor high minima.

The temperature, ordinarily, on a night of inversion, of course, falls along the entire slope as well as on the valley floor, but with increasing elevation it falls less and less, and the center of the belt rises steadily from nightfall to dawn.

Influence of Mountain Breeze.—The minima in the valleys are sometimes affected by the mountain breeze, but the observations show that this wind does not develop except where the mass of the mountain around the summit is great. Breezes do not blow down the sides of a mountain from a mere knob, but where the mass is great, as at Altapass on the main Blue Ridge, or at Tryon, the breeze is frequently observed. The mass being freely exposed with its great surface, like an elevated plateau, becomes covered at night with a blanket of cool air and, if the prevailing wind is favorable, after a time this cold air moves down the side of the mountain in a water-like flow, being mechanically warmed in its descent but, nevertheless, serving to lower the temperature, at least for a time, on the slope, although raising it in the valley below where the temperature has already fallen to a

low point. If the wind generally is blowing from an opposite direction, the mountain breeze does not develop, even though other conditions are prevalent. Of all the places used in the research, Tryon afforded the best examples of the effect of the mountain breeze. The observing stations at that place were located on Warrior Mountain, overlooking the village of Tryon, and close to the summit was the Saluda Plateau. When the air at night became unusually cool over the higher levels, it was observed to flow down the gorge of the Pacolet River and continue on through the valley, the thermograph traces on the valley floor showing unusual fluctuations.

Seasonal Fluctuation of Inversion Conditions.—Inversions are most frequent during the months of May and November when the weather conditions are usually settled in the mountain region, long periods of fair weather then prevailing. They are somewhat more pronounced in the latter month because of the greater length of the night, the thermal belt rising as the length of night increases.

Inversions are almost as frequent during the summer months, but their range is small. In the winter months, when they are much less frequent, the range is great and the type during that period is usually Intermediate or Cyclonic, under the influence of rapid storm movement.

Weather Conditions Affecting Inversion.—During a period of fair weather the amount of inversion is observed to increase steadily up to about the fifth night because air over the valley enclosed by the mountains becomes steadily warmer during the day, so that it has a larger and larger amount of warm air available for interchange with the surface temperature on the adjoining slopes. The time of maximum inversion sometimes occurs later than the fifth day, but finally the peak is reached, because increasing vapor and impurities in the form of dust and smoke, interfere with radiation.

The observations show that the amount of inversion depends decidedly upon both relative and absolute humidity. When there is considerable water vapor in the atmosphere the amount of inversion is small, and when the air is dry the range is correspondingly large. A humid period is always characterized by a small average daily range in temperature along the entire slope, the variation being slight in the day as well as in the night. The vapor pressure controls the degree of inversion in that the loss of heat by radiation through moist air is small, while through dry air it is large.

Places of Highest and Lowest Minimum Temperature.—The place of actual highest minimum in the mountain region largely depends upon elevation above sea level, because the lower the altitude the warmer the free air becomes in the daytime under the influence

of the sun's heat. So we find in the Carolina mountain region among the places employed in this research the highest average minimum on the slope at Tryon at an elevation of 1,350 feet above sea level and about 400 feet above the valley floor.

On the other hand, the lowest average minimum is found at a station at Highlands in a cove or frost pocket at an elevation of approximately 3,600 feet above sea level. However, in comparison with its altitude, this does not have the lowest average minimum for the entire region, as that is found at Blantyre on the valley floor of the French Broad River. The valley there is of considerable width, the grade is very slight, and towering mountains are in the distance, although no high peaks are close by. The bottom lands are marshy with dense vegetation, thus affording a vast area of radiating surface, with no opportunity for horizontal interchange with the warm free air above.

While the minimum averaged the lowest at the base, or valley floor station at all places employed in this research, occasionally, of course, the temperature at night was lower at the summit during "reversion" conditions. This was especially pronounced with strong west to northwest winds, bringing in cold waves. During such conditions the lowest minima at two of the places, Tryon and Altapass, occurred at the summit where the mass is great, but the lowest absolute minima for the entire region, —7° at Highlands and —6° at Blantyre, were observed at base stations under the anti-cyclonic type of inversion.

Damaging Effect of Changeable Temperature and Shortness of Season.—Fruit growing in the North Carolina mountain region, in spite of the thermal conditions referred to, is more or less hazardous. This is mainly due to the protracted periods of warm weather which often prevail during the wintertime, or early spring, swelling the buds and even forcing them open, only to be followed by disastrous freezes. The injury from this cause is seldom marked in the lowest levels, but is more serious at altitudes of 2,000 feet and above. In both the years 1913 and 1916, there were protracted warm spells in January followed by severe cold in February, and the buds were seriously damaged. Moreover, in the springs of these years additional freezes occurred after prolonged warm spells at the upper and middle levels; and, as a consquence, the fruit crop of the year was poor over the larger part of the area. Probably in no fruit growing section of the country is this phenomenon more frequently observed than in the North Carolina mountain region.

Again, in the higher levels, especially at places having an altitude of more than 3,000 feet, the season is comparatively short, there normally being freezes late in the spring and early in the autumn. At these places, at least, except on slopes, the growing season is usually so short that the fruit does not fully mature.

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RAINFALL OF THE GREAT PLAINS IN RELATION TO CULTIVATION*

J. WARREN SMITH

The land in the Great Plains States is easily cultivated and is naturally very fertile. Wherever sufficient moisture is available, either from rainfall or by irrigation, large crops are possible.

In eastern Texas, Oklahoma, and Kansas, and in southeastern Nebraska, the average annual rainfall is over 30 inches, and it is so well distributed that serious droughts are not of frequent occurrence.

In eastern New Mexico, Colorado, and Wyoming, extreme western Texas, Oklahoma and Kansas, western Nebraska and South Dakota, central and western North Dakota, and eastern Montana, the average annual rainfall is between 10 and 20 inches and droughts are frequent. In the years of light rainfall, or poor distribution there is not sufficient moisture for crops unless irrigation is possible. Even in the region where the annual rainfall averages between 20 and 25 inches, crops suffer in the years of light or poorly distributed rainfall. This is particularly true in the southern portion of the Great Plains where the summer temperature is high and evaporation is, consequently, greater than in the northern part. The 20-inch average annual rainfall line follows roughly the 100th meridian of longitude, being considerably west of it in Texas and Oklahoma, slightly west in Kansas and Nebraska, slightly east in South Dakota, and considerably east in North Dakota, as is shown in figure 1.

As a well-distributed rainfall of about 20 inches each year is necessary for crops, unless irrigated, it follows that the western Great Plains form a rather critical region for growing general farm crops. Even when the so-called dry-farming practice is resorted to, crop failures are not unknown.

Disregarding the arguments which might be presented to show that the effect of cultivation in the semiarid region must be negligible in causing the variation in temperature and humidity necessary to produce an increase in the amount of rainfall, we have turned our attention to ascertaining whether there has, or has not, been an increase in the precipitation over the Great Plains. All available rainfall records in that district were collected, tabulated, and charted in the accompanying graphs:

Figure 2 (A) shows curves of the annual rainfall, and the successive and progressive 5-year averages of the annual rainfall from

* Also published in *Monthly Weather Review*, December, 1919.

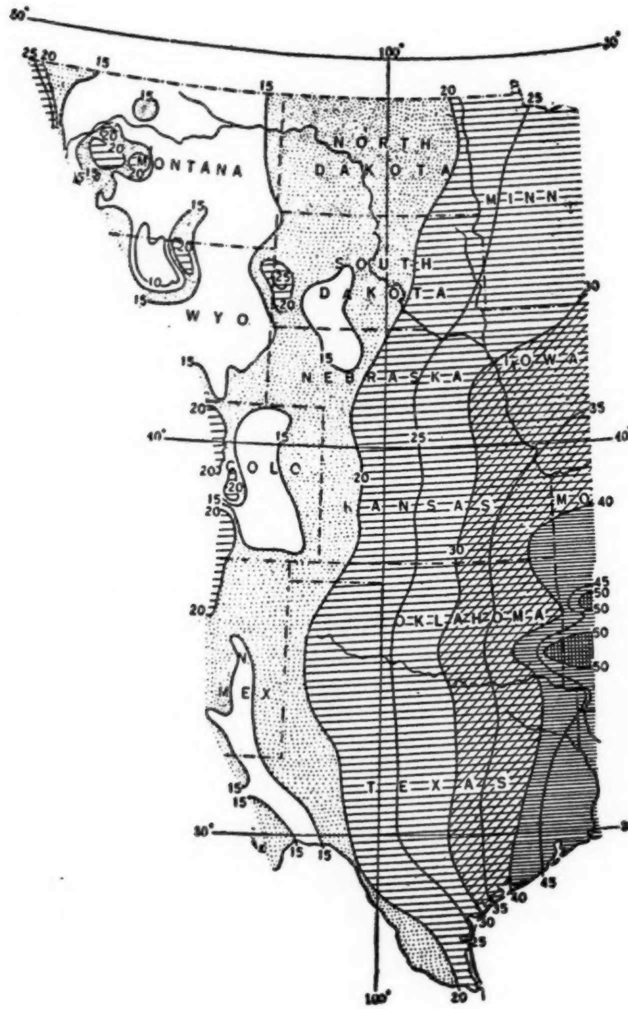

FIG. 1. Map showing the average annual precipitation in that part of the United States lying between the 93d and the 113th parallels of longitude. (From advance folio, Atlas of Amer. Agric.)

1867 to 1917, inclusive, for North Dakota, South Dakota, western Minnesota, and central and eastern Montana. Care was taken in this, as well as in the data for the other curves, to keep the stations well balanced between the wetter eastern and drier western parts of the districts.

The curves in A show a rise in the rainfall amounts from the early to the late seventies, followed by a rather sharp decrease to about 1889-90, and then a uniform increase until 1905 and 1906, and after that a moderate decrease.

The average annual rainfall for the first 25 years of this period is 19.6 inches and for the last 25 years 19.4 inches. The average precipitation for each 10 years, beginning with 1868, is shown in Table 1.

Table 1.—Precipitation for each 10 years from 1868 to 1917, inclusive, in the northern Great Plains.

Period	Precipitation (Inches)
1868–1877	19.8
1878–1887	20.4
1888–1897	18.0
1898–1907	19.5
1908–1917	19.1

Diagram B gives similar curves for the same period for Nebraska, central and western Kansas, eastern Colorado, and southeastern Wyoming. This indicates a wider variation in the annual rainfall than in the northern States, but the same two crests in the curve. One striking difference between them, however, is that, while in A the first crest was centered in 1877 to 1879, in B it was not reached until about 6 years later. As the second crest comes at about the same time in the two areas, the time between the two crests is 29 years in the northern area and only about 23 years in the central.

The average precipitation for the first 25 years of the period in the Central Great Plains was 18.4 inches, and in the second 18.7 inches. The average for each 10 years is given in Table 2.

Table 2.—Precipitation for each ten years from 1868 to 1917 inclusive in the central Great Plains.

Period	Precipitation (Inches)
1868–1877	16.3
1878–1887	20.4
1888–1897	17.6
1898–1907	20.2
1908–1917	18.2

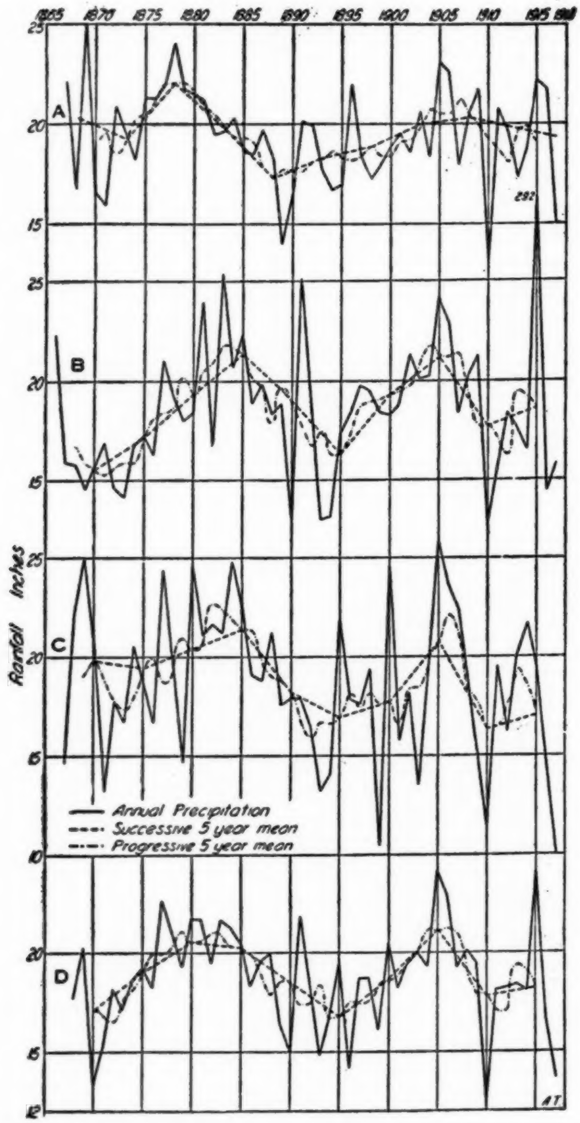

FIG. 2. Curves showing the average annual precipitation in (A) The Dakotas, western Minnesota, central and eastern Montana and northeastern Wyoming, 43 stations; (B) Nebraska, central and western Kansas, eastern Colorado, and southeastern Wyoming, 38 stations; (C) western Oklahoma and Texas, and central and eastern New Mexico, 40 stations; (D) average of the above, 121 stations.

In graph C there are similar curves for the southern Great Plains States, including western Oklahoma and Texas and eastern New Mexico. The first crest in this 50-year curve is at about the same time as in the central division, while the middle depression is slightly later than in either of the others.

The average annual rainfall for the 25 years from 1868 to 1892, inclusive, was 19.8 inches; for the next 25 years only 17.8 inches. The average for each 10 years is shown in Table 3.

Table 3.—Precipitation for each 10 years from 1868 to 1917, inclusive, and for the 12 years from 1852 to 1862 and 1867 in the southern Great Plains.

Period	Precipitation (Inches)
1852–1862 and 1867 (12 years)	18.8
1868–1877	19.6
1878–1887	20.8
1888–1897	17.5
1898–1907	19.3
1908–1917	16.7

In graph D the data, from which graphs A, B and C were prepared, were averaged so that this shows the annual and progressive and successive 5-year mean precipitation for the whole western Great Plains region.

This indicates two well-defined crests in rainfall about 25 years apart, with the low part of the curves at the beginning, middle, and end of the period of 50 years.

The average precipitation for the 25 years from 1868 to 1892, inclusive, was 19.2 inches, and from 1893 to 1917, inclusive, 18.4 inches. The average for each 10 years is shown in Table 4.

Table 4.—Precipitation for each 10 years from 1868 to 1917, inclusive over the western Great Plains.

Period	Precipitation (Inches)
1868–1877	18.1
1878–1887	20.4
1888–1897	17.5
1898–1907	19.9
1908–1917	18.4

There has been a decided increase in the area under cultivation in the Great Plains States during the past 50 years as brought out by figures in Table 5.

If increasing the area under cultivation in any district increased the precipitation, we should expect a steady rise in the annual rainfall amount over the region covered by this study. Instead of finding a regular increase, the graphs in Figure 2 make plain that there are

well-defined but comparatively short periods of increasing and decreasing rainfall, but which can not be due to cultivation. The crop area is being extended into the drier region because of crop adaptation and better farming methods. Moisture is conserved that formerly ran off, dry-farming methods are being adopted, and crops better adapted to the region are being planted.

An interesting fact in connection with the precipitation records is that dry years occasionally occur during a wet period or wet years in a dry period. This is brought out by the light rainfall in 1882 in graph B, and the very heavy rainfall in 1915 in graph D.

Table 5.—Acreage of certain grain crops in the Great Plains States.

Crop and State	Year			
	1867	1882	1892	1917
	Acres	Acres	Acres	Acres
Barley:				
Kansas	224	20,882	13,901	750,000
Nebraska	222	156,000	90,223	213,000
The Dakotas	...	28,273	321,693	2,845,000
Montana	...	1,852	5,032	90,000
Corn:				
Kansas	211,373	4,280,430	5,952,057	9,156,000
Nebraska	64,583	2,364,120	5,572,523	9,240,000
The Dakotas	...	186,247	811,526	3,940,000
Montana	...	492	1,080	81,000
Oats:				
Kansas	6,555	472,619	1,547,175	2,284,000
Nebraska	11,479	400,119	1,615,393	3,038,000
The Dakotas	...	140,000	1,174,449	4,500,000
Montana	...	28,000	66,323	680,000
Wheat:				
Kansas	89,285	1,573,000	4,070,724	3,737,000
Nebraska	9,917	1,657,000	1,253,564	997,000
The Dakotas	...	720,000	5,410,077	10,716,000
Montana	...	42,812	41,761	1,727,000

The opinion is expressed by some students of weather data that dry and wet years come in groups of two or three each, but this belief is not substantiated by these charts. In other words it is not possible to predict what the total precipitation for any year will be from past records. A wet year may be followed by another wet one or by a very dry year or vice versa. For example the dry year in 1890, in graph B, was followed by one of the wettest in the whole period, while the dry year of 1913 was followed by one equally dry.

In graph D it will be seen that the wet year of 1877 was followed by one nearly as wet; that of 1891 by a rainfall not far from the normal; that of 1905 by another wet year, and 1915, by one with considerably less precipitation than the normal.

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FEATURES OF GLACIAL ORIGIN IN MONTANA AND IDAHO

A Shaler Memorial Study

W. M. DAVIS

CONTENTS

INTRODUCTION: *The Transcontinental Excursion of* 1912.—When the Transcontinental Excursion of 1912, organized by the American Geographical Society in celebration of its sixtieth anniversary, was passing northwestward through the Rocky Mountains of Montana in September of that year, several members of the party were imprest, as we ran down the valley of Flathead River to its continuation in that of Clark Fork, one of the larger valleys of the Columbia system, with the change from the normally dissected valley sides of the upper branches to the scourd and oversteepend valley sides, increasingly developd down the main stream, as if due to erosion by a glacier that had advanced southeastward up the valley. The change began with the laying bare of soil-stript rocks to a small height above the valley floor without noticeable alteration of hill-side form; then came the scouring and plucking of ragged ledges in the basal slopes to a height of several hundred feet, whereby the concave descent of the normal spur-ends was steepend to a convex descent; a few miles farther on the changes became more pronounced in the deep channeling and partial truncation of the spurs; this continued with steadily increasing strength, until after twenty or thirty miles the spurs were strongly truncated, and so continued farther toward Lake Pend Oreille in northern Idaho. The oversteepend

valley walls, surmounted by rounded summits with normally graded slopes and indented at the top by hanging valleys of normal form, descended to the broadly aggraded valley floor in bold and often precipitous cliffs sometimes a good thousand feet in height. What we had at first suspected, we were then prepared to assert with confidence:—a mature valley of normal form, deeply incised in a mountainous highland, gradually becomes an overdeepend glacial trough, and the glacier which excavated the trough, must have advanced up stream southeastward. Mr. R. W. Brock, then director of the Geological Survey of Canada, who was a member of our party, suggested that the invading ice was a branch of a Canadian glacier, which had crost the international boundary by an open pass on its way southward from the higher mountains of the north. It later appeard that the branch glacier, which had thus come to invade the valley of Clark fork against the flow of its river, had been recognized as the barrier of a temporary proglacial lake—Lake Missoula—first described by Pardee in 1910, the numerous and faint, high-level shorelines of which we had seen, before reaching the scourd part of the valley, on certain treeless mountain slopes in the branch valleys of Upper Clark fork in Montana. It then came to mind that, if this were true, the branch glacier that ascended the main valley of Clark fork must, towards its southeastern extremity where its scouring reachd but a few hundred feet up on the valley sides, have rested on the bottom of the valley under a thousand feet or more of lake water; for the highest shorelines, which could have been made only at the time of the greatest glacial advance, lie at some such height above the level at which the scourd spur-ends were first seen. If this should prove to be the case, it would afford a striking confirmation, and indeed an extension of Gilbert's theory that glaciers which scour out fiord troughs rest so firmly on the trough-bottom that no water can enter underneath to buoy them up, and that they therefore press upon the trough bottom with their entire weight, and continue to be effective eroding agents hundreds of feet below sea level.

A Visit to Clark Fork in 1913.—In order to test this point I revisited the valley of Clark fork in August, 1913; a grant for this purpose having been allowd me from the Shaler Memorial Fund of Harvard University, for which I hereby express my grateful appreciation. The reconnaissance of 1913 was not limited to the valley of Clark fork, but extended into several other valleys of Idaho and Montana, and into Canada along the deep intermont depression occupied by Lake Kootenai, from which the great Canadian glacier came southward into the Pend Oreille region. Confirmation was thus found for Brock's general suggestion regarding the Canadian source of much

of the ice in the valleys south of the international boundary, a suggestion which has since been found to be antedated twenty years or more by the views of several other geologists. It was furthermore found that the highest shore lines of Lake Missoula stand from 1,000 to 1,700 feet above the base of the truncated spurs in Clark fork valley. Hence it appeard that the truncation of the spurs was the work of a deeply submerged glacier; and this glacier was then believd to be a long and narrow branch of the greater glacier which came from the long trough valley of Lake Kootenai.

The preparation of the present essay was delayed by my voyage across the Pacific on a Shaler Memorial study of coral reefs, which occupied most of 1914, and by work on observations then made after my return home. After the manuscript was completed in 1915 it was long held by the censors to whom it was submitted by the editor, according to the rules of our Association; and after it was returnd to me with the censors' comments, still further delays intervened for a time in connection with the Great War. Altho publication has been in this way long postponed, the description of the facts observd still holds good, and the discussion of the facts has been improved by seasoning, as will appear below. The belated and revised essay is therefore now offerd to the scientific public.

Modifications of First Conclusions.—Certain important modifications of my previous conclusions were urged by one of my censors. First, to the effect that the glacial erosion in the valley of Upper Clark fork, which I had attributed to the up-stream advance of a long and narrow distributary branch of the main Kootenai-Pend Oreille glacier, should be ascribed at least in part to glaciers of more local origin and less length. The reasons offered for this modification were on the one hand that my observations did not suffice to prove the continuity of a single glacier; and on the other hand that it was physically impossible for a long and narrow glacier to advance so far up a valley of somewhat irregular form. Second, to the effect that a glacier could not possibly remain submerged in an ice-bard lake and there continue its erosional work in the manner that I had been driven to suppose. These comments appear to me to have much weight; indeed I had previously found difficulty myself in accounting for so long an advance of a branch glacier up a comparativly narrow valley against gravity, and for its remaining submerged while it eroded the valley sides; but the possibility of independent sources for one or more local Clark fork glaciers had not occurd to me; and the submergence of the eroding glacier seemd a necessity because it was assumed to be synchronous with the submerging lake. After careful consideration, both of these chief modifications have proved to be

helpful, and they are therefore welcomed in the final revision to which the essay has been submitted. They are essentially incorporated in its present form. It may be remarkd in passing that the improvement of the essay thus gained is, in my opinion, a strong recommendation for the censor system adopted by our Association; and also that personal credit would gladly be given here for the improvement, had not the censor to whom it is due preferd to remain anonymous.

OUTLINE OF ESSAY. *Subdivision of the Region.*—The Rocky Mountain system in Montana and Idaho, between the Great plains on the east and the Columbia lava plateau on the west includes a number of ranges and plateau-like highlands of deformd crystalline and stratified rocks, which frequently show even skylines and thus strongly suggest that they represent a formerly worn-down mountain system, irregularly warpt and uplifted again in narrower or broader belts of less or greater altitude, the higher belts being now maturely dissected, while the lowest ones are more or less aggraded. A serviceable review of the physiographic history of the mountains has been prepared by J. L. Rich.[1] The larger features of relief thus produced generally trend about north and south, or northwest and southeast, and reach altitudes of 8,000, 9,000, or 10,000 feet. The higher mountains show abundant signs of strong sculpturing by local glaciers, and two of the largest intermont depressions—those of Flathead lake on the east and of Kootenai and Pend Oreille lakes on the west—bear the manifest records of strong erosion and of heavy deposition by broad south-moving glaciers from the Canadian mountains.

For our present purposes the mountainous area of northwestern Montana and northern Idaho may be divided as in Fig. 1, following the nomenclature of Daly[2] and other writers, into three chief members, divided by the two intermont depressions just mentiond. These five large features all extend northward into Canada. The eastern member includes several ranges of the Rocky Mountains proper which next south of the international boundary rise in the sharpend Alpine peaks of Glacier National Park; their westernmost elements in our district are the Galton and Swan ranges. The middle mountainous member includes the southern extension of the Purcell range from Canada into the Cabinet and Flathead mountains of Montana; the mountains last named being separated from the Purcell range by the transverse valley of Kootenai river on its course from the eastern

[1] J. L. Rich, An Old Erosion Surface in Idaho; Is It Eocene? *Econ. Geol.*, XIII, 1918, pp. 120-136.

[2] R. A. Daly, The Nomenclature of the North American Cordillera, *Geog. Jour.*, XXVII, 1906, pp. 586-606.

to the western intermont depression. The westernmost member includes the Selkirk range of Canada and its dependencies in northern Idaho.

The Two Longitudinal Depressions.—The eastern one of the two long depressions is for the most part broadly aggraded with glacial deposits; it extends into Canada as the long and narrow Rocky Mountain trench in which the Columbia and the Kootenai rivers head against each other and flow in opposite directions, only to join each other far to the west after flowing thru irregular transverse valleys. The part of the eastern depression that lies in Montana has an extension of 110 miles south of the boundary, and a breadth of from 12

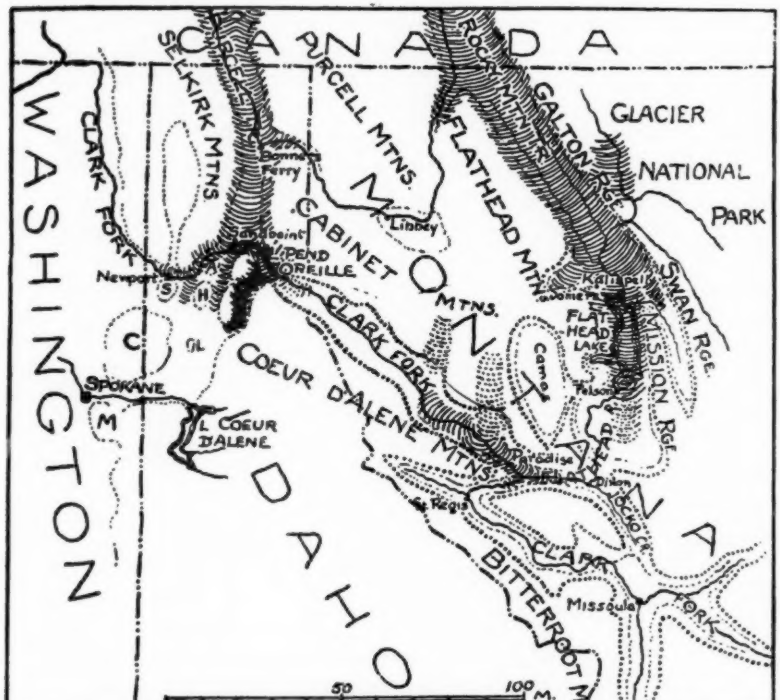

FIG. 1. Outline map of region.

to 30 miles; it will here be calld the Flathead trough, after the lake that it contains and the river that drains it southward; its southern part is divided by the Mission range of which I have given account elsewhere[3] into a narrower and shorter eastern branch, draind north-

[3] W. M. Davis, The Mission Range, Montana; Proc. Nat. Acad. Sci., 1915, pp. 626-8; also, *Geog. Rev.*, II, 1916, pp. 267-88.

ward by Swan river to Flathead lake, and a broader and longer western branch which is draind southward thru Flathead lake by Flathead river. Flathead lake, about 2,900 feet in altitude, 27 miles long north and south, by from six to fifteen miles wide east and west, with no authentic soundings that I could discover but reputed to be several hundred feet deep, occupies the northern half of the western branch, with the town of Somers at its northwestern angle, five miles west of Flathead river inlet, and the town of Polson at its southwestern curve near the outlet. Kalispell, the chief town of an agricultural district, lies on the broadly aggraded plain ten miles north of the lake.

Kootenai river, following the Rocky Mountain trench southeastward, turns southwestward just after crossing the international boundary, and thus for forty miles obliquely traverses the middle mountainous member, from which it escapes by turning a right angle into another oblique course of fifty miles to the western depression. This irregular transverse valley is taken, as above noted, to mark the southern limit of the Purcell range. The Great Northern railway, which traverses the eastern ranges by following valleys of the Flathead system south of Glacier National park, originally crost the Flathead depression southwestward, and then made its way thru the Flathead mountains by comparatively open valleys to the right-angle turn of Kootenai river at the southernmost point of the Purcell range; but now the Flathead depression is followd northwestward over an open valley-floor divide to the Kootenai river, and this river is then followd in all its irregular course thru the middle mountains to the western depression. The railway thus increases distance but saves grades.

The narrower western depression is known in Canada as the Purcell trench: a good part of it is occupied by Kootenai lake, 1,760 feet in altitude, 65 miles in length and two or three in width, with a reported depth of 800 feet; the southern end of the lake is twenty miles north of the international boundary. The depression branches irregularly at its southern end among various mountain masses in northern Idaho; the western branch is followed by the lower course of Clark fork after it flows out of Pend Oreille lake, the southwestern branch broadens and opens upon the Columbia lava plateau at Spokane; the long southeastern branch is the valley of Clark fork with which we are here especially concernd; the southern or central branch is occupied by Pend Oreille lake, 2,051 feet in altitude, 24 miles in length north and south, by two or three miles in width, with a sounding, reported as trustworthy, of 1,300 feet: the southern part of the depression will be here named after this lake. The town of Sandpoint at the northern end of the lake lies on the aggraded floor of the depression fifty miles south of the international boundary; the aggraded section

of the depression continues north to Kootenai lake. Kootenai river, after entering the depression from the east twenty miles south of the boundary, turns north-northwest along it to the lake of the same name; the town of Bonners Ferry lies at the river turn, which will be here named the Bonner elbow of the river. The parts of the two great depressions here chiefly referd to may be given the river-and-lake names, Kootenai-Flathead and Kootenai-Pend Oreille.

Flathead River and Clark Fork.—Flathead River, after leaving its lake, flows thru the broad western branch of the Flathead trough and then cuts thru a low range for a few miles to a well defined valley of varying width, trending in general from southeast to northwest and lying between the Cabinet and Flathead mountains on the north and the Coeur d'Alene and Bitterroot mountains on the south; here it receives Jocko creek from the southeast, and then bending square to the west-northwest—the village of Dixon lies at the bend—it joins Clark fork twenty miles farther on, at the second apex of a sharp backhanded turn or zigzag by which this river shifts from one northwestward course to another. Clark fork, formerly called Missoula river, is now justly known by the name given to it over a hundred years ago by one of its earliest explorers in honor of his companion. It brings down the drainage from a large mountainous area on the southeast, where one of its chief branches is the Bitterroot, coming from a fine valley on the south. Reinforced at its backhanded turn by the Flathead, it continues eighty miles northwestward along the extension of the well-defined Flathead valley of western Montana—the valley mentiond at the opening of this paper—thru the mountainous highlands to the northern end of Lake Pend Oreille in Idaho. Clark fork is followd by the Northern Pacific railway in a continuous down grade from its headwaters for 200 miles to the lake; but in order to save distance at the expense of grade, a short-cut has been made for passenger trains, from the junction of Bitterroot river, where the town of Missoula is situated, over Evaro pass, 3,971 feet, to the headwaters of Jocko creek and then down a section of Flathead river, joining the original line on the main river at its backhanded turn or zigzag. The railway division station of Paradise lies a mile below the junction. The village of St. Regis lies at the other apex of the zigzag river course.

Clark fork continues as the outlet of Pend Oreille lake, and thus flows thirty miles westward thru the isolated ranges of the westernmost mountain belt into the Columbia plateau of heavy lava flows, where they overlap the western flanks of the mountains, thus passing from Idaho to Washington. Here the river turns to an entrenchd northward course for fifty miles, and at the international

boundary joins the Columbia river which there comes southward from the Canadian valleys. The part of the river below Lake Pend Oreille will be here spoken of as Lower Clark fork; and the part above the lake as Upper Clark fork. The Great Northern railway turns southward from Bonners Ferry to Sandpoint at the north end of Pend Oreille lake, follows the lake outlet for 25 miles to the Idaho-Washington line, where the town of Newport is situated, and then runs southward forty miles to the city of Spokane. The Northern Pacific railway rounds the north end of the lake and takes a more direct course to the same city; the Rocky Mountain division of the Chicago, Milwaukee and St. Paul railroad, which parallels the Northern Pacific for many miles along the valley of Upper Clark fork, reaches Spokane by a more direct course from the St. Regis apex of the Clark-fork turn, over the mountains of the Coeur d'Alene mining district. The Oregon Railroad and Navigation Company's line reaches Spokane from the southeast, and the Canadian Pacific sends a branch line southwestward thru our district past the Bonner elbow of Kootenai river and the northern end of Pend Oreille lake, in order to reach the growing metropolis of the "Inland Empire."

Two Great Canadian Glaciers.—The traces of the two great Canadian glaciers, here to be called the Kootenai-Flathead and the Kootenai-Pend Oreille, are easily followd southward from Canada along the great intermont depressions into the Flathead and Pend Oreille troughs; the paths of tributary glaciers may be traced back into the higher mountains adjoining the great depression; the eastern depression is associated with the strong glacial features of Glacier National Park south of the international boundary. The traces of the eastern or Kootenai-Flathead glacier cover a greater breadth, east and west, and extend somewhat farther south than those of the western or Kootenai-Pend Oreille glacier. It is in connection with an outgoing branch or distributary of the latter glacier, the traces of which extend into the valley of Upper Clark fork where it may have had local reinforcement, that the sublacustrine glacial scouring in the vanisht Lake Missoula is considered in the latter part of this essay.

The southern limit of the broad Kootenai-Flathead glacier is markt by two great terminal moraines, one strong and fresh looking, the other farther south and of softer contours, in the southern part of the Flathead trough; inside (north) of the younger and more northern moraine, here to be called the Polson moraine after the town on its inner slope, lies the existing Flathead lake; to the older and more southern moraine the name of Mission will be given, after the long-established Mission of St. Ignatius, which lies a little farther southeast.

The southern extensions of the Kootenai-Pend Oreille glacier are traceable along its several distributary branches, separated by intermediate mountains, as will be described in a later section.

ITINERARY. *The Outward Journey.* The description of various features on later pages will follow the order of their physiographic relations, not that of their observation, which may be inferd from the following itinerary. Most localities here mentiond are indicated on Fig. 1. After leaving Cambridge on July 27, 1913, and making several stops on the way, I reached the Rocky Mountains and crosst the continental divide west of Helena, Montana, by the tunnel under Mullen pass (5,800′) on the Northern Pacific railway in the morning of August 2. Thus an upper valley of the Clark fork-Columbia drainage system was entered at its very head. That afternoon I left the train just below the junction of Flathead river with Clark fork at the railway division station of Paradise, where three days were given to local excursions on foot and by rail. On August 6, I went by train ninety miles northwestward down the valley of Upper Clark fork—stops being made at two stations on the way—to the northern end of Pend Oreille lake, around which the railway turns to a southwestward course of sixty miles to Spokane, on the eastern border of the Columbia lava plateau a few miles within the State of Washington. August 7 was spent in Spokane, and August 8 on Lake Coeur d'Alene in the mountains thirty miles east of Spokane; the nights of August 8, 9, and 10 were past most agreeably at Hayden lake, thirty miles east of Spokane and ten miles north of Coeur d'Alene, at the beautiful country seat of one of my students of thirty years ago. Automobile excursions on August 9 and 10 showd me many interesting features in connection with the extensiv outwashd gravel plain of the Pend Oreille glacier.

The Return Journey.—On the morning of August 13 the return journey from Spokane was begun by the Great Northern railway, northeastward to the Bonner elbow in the Kootenai-Pend Oreille trough, where Kootenai river enters it from the east and turns north to Canada again. The train ride was continued into the transverse valley of the Kootenai and back to Bonners Ferry in the afternoon. On the next day a roundabout excursion was made by the Canadian Pacific railway northeastward and westward to Kootenai lake in Canada, and back the day after to Bonners Ferry. August 15 was given to the broad valley of Kootenai river between Bonners Ferry and Kootenai lake. That night the eastward journey was continued by the Great Northern railway to Belton, the western entrance to Glacier National Park, and the next day was spent in the Park on

Lake McDonald. On August 18 a turn was made southwestward across the broad plain of Flathead trough to the town of Kalispell not far north of Flathead lake; that afternoon Mr. H. F. Smith, a Harvard student, took me on an interesting excursion to a lateral moraine of the great Kootenai-Flathead glacier near the north end of the Mission range; the night was spent at Somers at the northwest angle of Flathead lake. On August 19, a steamboat carried me 27 miles to Polson at the southern end of the lake, where an automobile was taken 35 miles farther south to Ravalli station of the Northern Pacific railway on Jocko creek. The next day I went by train a few miles farther up the valley to Arlee, where a cut was made for me with pick and shovel in one of the faint shorelines of Lake Missoula, and it was thus learnd that the faintness of the shorelines is largely due to their having been obscured by downhill wash or creep of detritus. Return to Polson was made by train and automobile the same afternoon. On August 21 the Polson moraine was examined on foot in the morning; steamboat and train carried me in the afternoon back to Kalispell, where excursions were made the next day to the steepend spur ends of the Swan range on the eastern side of the Flathead trough, and into the margin of the lower mountains on the western side of the trough. The return journey was resumed by the Great Northern railway on August 23, and continued from Duluth by steamer to Detroit. Cambridge was reached on September 3, 1913.

Some of the observations set forth in the following pages were made from the windows of running trains or the deck of a passing steamboat. Estimates of local relief are rough, and I fear in some cases far from accurate. Evidence of glacial sculpture was provided almost entirely by peculiarities of mountain-side form, occasionally by the presence of moraines and boulders, and only rarely by striated rock surfaces. Most of the sketches here reproduced are simplified diagrams rather than accurate pictures; their details are more or less fanciful, for it was impossible to make finished drawings on the spot. Members of the forest service in particular must find fault with them for the omission of many trees and groves; yet the hill and valley outlines may serve as a helpful supplement to verbal description.

Literature and Maps,—A number of articles that give information regarding the region visited are referred to in later paragraphs. Important among these are:—Daly's essay on the Nomenclature of the North American Cordillera,[4] Calkins' bulletin on a reconnoissance in northern Idaho and northwestern Montana,[5] Pardee's account of the

[4] R. A. Daly, The Nomenclature of the North American Cordillera, *Geog. Jour.*, XXVII, 1906, pp. 586-606.

[5] F. C. Calkins, Geological Reconnaissance in Northern Idaho and Northwestern Montana, *Bull.* 348, *U. S. Geol. Surv.*

Glacial Lake Missoula,[6] Elrod's account of the Flathead lake district,[7] and certain pages of the Guide-book of the Western United States, Part A, Northern Pacific Route.[8] During the discussion of my notes, I have had the advantage of conferring with Mr. R. W. Stone, of the United States Geological Survey, who contributed an account of Glacial Lake Missoula to the Princeton meeting of the Geological Society of America, January 1, 1914.

The larger part of the region visited on my excursion is not yet coverd by the topographic maps of the U. S. Geological Survey. The headwaters of Clark fork are included in the Ovando, Coopers Lake, Missoula, Bonner, Helena, Hamilton, Sapphire and Philipsburg quadrangles, all in Montana; some of the Flathead sources are shown on the Kintla Lakes and Chief Mountain quadrangles in Glacier National Park, also in Montana: Lakes Pend Oreille and Coeur d'Alene are mostly covered by the Sandpoint, Priest Lake, Rathdrum and Cataldo quadrangles, Idaho; and the Spokane district by the Spokane and Oaksdale quadrangles, Washington. The valley of Upper Clark fork, and the broad Flathead trough are not yet mapt. A rough map of the Flathead district, based on the surveys of the Land Office has been publishd, but is not now easily obtainable.

Order of Description.—The physiographic descriptions of the following pages will begin with an account of the Kootenai-Flathead depression south of the international boundary, where the records of a broad glacier of Canadian origin are relatively simple and manifest. An account of the Kootenai-Pend Oreille depression comes next, including the striking features of Kootenai lake north of the boundary, as well as the more complicated features of the several distributary arms to which this great depression leads. A number of detaild features associated with the extensiv gravel plain southwestward from these arms will then be briefly described. The features due to glacial erosion in Upper Clark fork valley follow next, and the shorelines of Lake Missoula, bard on the west by the Kootenai-Pend Oreille glacier, will be considerd in the closing pages.

The Kootenai-Flathead Depression. *Its Northern Extension.* —No account that I have found of the Canadian portion of this depression does justice to the great amount of glacial erosion which it records, if it be in that respect at all comparable with the Kootenai-Pend

[6] T. J. Pardee, The Glacial Lake Missoula, *Jour. Geol.* XVIII, 1910, pp. 376-86.

[7] M. F. Elrod, A Biological Reconnaissance in the Vicinity of Flathead Lake, *Bull. Univ. Montana*, Biol. Ser., 1902, pp. 91-182.

[8] M. R. Campbell and Others, Guidebook of the Western United States, Part A, The Northern Pacific Route, *Bull.* 611, *U. S. Geol. Surv.*

Oreille depression farther west. My own views of its northern portion are limited to two traverses on the Canadian Pacific railway, first in 1897, before I had learnd to recognize the larger forms of glacial sculpture, and again in 1909, when such forms had acquired a fuller meaning; but both traverses were rapid and the views allowd were incomplete. South of the international boundary the depression soon widens to a basin-like breadth in the district of Flathead lake, where its aggraded floor, standing at an altitude of nearly 3,000 feet, has a width of twenty or more miles.

Normally Eroded Valleys of the Swan Range.—The special interest of these ranges, the westernmost members of this part of the Rocky Mountains proper, in the present connection turns on the truncation of their western spurs. As the ranges are believd to be limited on the west by a fault, the movement on which separated the broad Rocky Mountain mass from the Flathead depression, the truncation of the spurs might at first thought be ascribed to faulting: but a closer examination of the case leads to the opinion that whatever fault scarp may have once existed here has been so maturely dissected into ravines and spurs that no trace of its face remains visible; and that the truncated spur ends are the result of lateral scouring by the great Kootenai-Flathead glacier. The truncation of the spurs is best seen on the Swan range for some ten or fifteen miles south of the deep notch where Flathead river, after gathering its branches from various longitudinal valleys within the mountains, makes its escape to the broadly aggraded plains of the depression-floor on the west. There the Great Northern railway also leaves the mountains, which it enterd by the singular pass at their eastern base, where the slow ascent for hundreds of miles across the Great Plains is suddenly exchanged for a rapid descent into a steep valley head of a Flathead branch. The truncated spurs at the western base of the mountains are seen to the south just before reaching Columbia Falls station on Flathead river, west of its deep notch.

The automobile trip that I made from Kalispell nearly to Flathead river notch and thence southward to the last of the truncated spurs persuaded me that their form is due to glacial erosion and not to faulting; for the truncation weakens southward, and about where it ends a broad belt of morainic hills departs from the mountain base and swings obliquely across the valley of Swan river, east of the Mission range. The higher slopes of the Swan range, as seen from the basin plain on the west, Figs. Nos. 2, 3, and 4, exhibit as a rule forms of mature normal dissection, with few, if any, indications of structural guidance in the determination of ridges or ravines. The crest is for the most part moderately sinuous, but in certain

stretches it is remarkably smooth, as if it there still retaind uplifted and unconsumed areas of the old mountain form,—perhaps deserving to be called a peneplain,—which characterizes so many of the highlands hereabouts. Where the retrogressiv encroachment of opposing interior and exterior valleys has resulted in producing notches in the crest line, they are not as yet deeply incised. Some of the valley heads are widend in cirque-like form, and continued downward in open troughs, apparently the results of feeble local glaciation; but the troughs are replaced by normal valleys toward the range base. The spurs, above the trough walls and trough sides, are altogether of normal form, down to the truncation of their lower ends. Some of the spurs seem to descend from advancing, high-level, promontory points of the apparently even highland surface that is indicated by the smoother parts of the crest line; other spurs head in summits that are isolated between notches. The spur ridge lines slope forward at angles of 20° or 30°. They present the variety of form usually seen

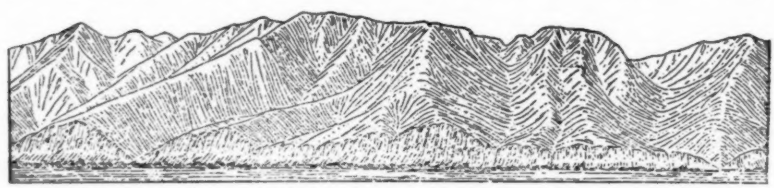

FIG. 2. Truncated spur ends, Swan Range, looking east.

in dissected scarps of fairly homogeneous rocks; for some are simply single spurs that descend between sub-parallel valleys from crest to base; some are tapering, dwindling spurs that lie between converging, confluent valleys, and therefore fail to reach the mountain base; and some lie between diverging valleys and broaden downward in a sprawling pattern, split into spurlets toward the base by short ravines. The consequent valleys and ravines vary appropriately to the variations of the spurs that remain between them. Some are single valleys of direct descent, enclosed by sub-parallel spurs from head to mouth; some converge from heads several miles apart to a single valley at the range base, being enclosed by sprawling spurs on either side and separated by dwindling spurs; some are merely short ravines that split the piedmont spurlets of large sprawling spurs. In short, the western face of the Flathead range presents the features characteristic of a maturely dissected fault scarp, such as I have described in certain stretches along the western face of the Wasatch range in Utah[9]; and it is because the Wasatch spurs are frequently truncated

[9] The Mountain Ranges of the Great Basin. *Bull. Mus. Comp. Zool.*, xlii, 1903, pp. 129-77; reprinted in Geographical Essays, Boston, 1909.

by terminal facets which have been with good reason regarded as residual parts of a great fault scarp that the question was raisd above as to the similar truncation of the Swan range spur ends; but the base of the Wasatch range has not been scourd longtitudinally by a great glacier.

Truncated Spur Ends of the Swan Range.—The terminal facets of the Swan range spurs were estimated to reach heights of 600 feet or more near Flathead river notch; but, as already noted, their height decreases southward, and the last one is not more than 100 or 200 feet high. The base line of certain truncating facets at the end of sprawling spurs may be half a mile or more in length; some of the smaller, spur-splitting ravines are cut off by the connecting wall of the greater facets, so that the ravines are left hanging in facet notches; but the larger valleys are cut down to the facet baseline. The upper part of the facets is inclined at angles of 60° or more and exhibits much bare rock, in strong contrast to the soil-coverd spur sides of less

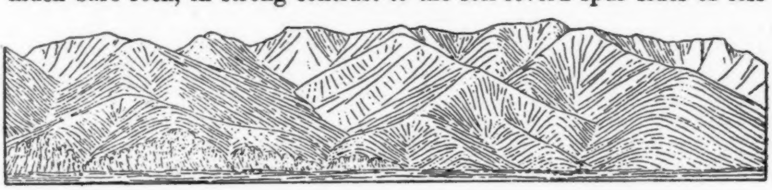

FIG. 3. Truncated and normal spur ends, Swan Range, looking east.

declivity above the facets; the lower part of the facets is flankt with talus. These visible facts of form may be about as well explaind by recent faulting as by recent glacial erosion; but if faulting is appealed to, it must be of much more recent date and of much smaller amount than the great fault by which the mountain mass is set apart from the adjoining depression, for the last of the truncated spurs is followd for a long distance farther south by long, trailing spurs, which descend gradually to the base line and fade away on the plain, thus showing that the main fault is relatively ancient; and it is in front of these dwindling spurs that the belt of moranic hills, springing from the range base near the last of the truncated spurs, swings obliquely away to the southwest. Recently renewd faulting as an origin for the spur-end facets is therefore improbable, for it can hardly be imagind that renewd faulting on an ancient fault line should terminate southward at just that part of a mountain front where the moraine of a great glacier, which decreasd in breadth toward its end, withdrew from the mountain base.

The Galton Range.—The Galton range north of Flathead river notch decreases in height for several miles and takes on an uneven crest line. I suspect that this change is due in part to the scouring overflow of a large branch glacier from the mountains of Glacier National Park. The western slope of the range there and farther north is much less dissected than farther south; and this difference I am disposed to attribute to a northward increase of scouring in the great Kootenai-Flathead glacier; the range front here, instead of being characterized by west-falling valleys and spurs, is markt rather by longitudinal benches, which I took to represent rock layers of somewhat greater resistance than their neighbors, brought into relief by the longitudinal scouring of a huge glacier.

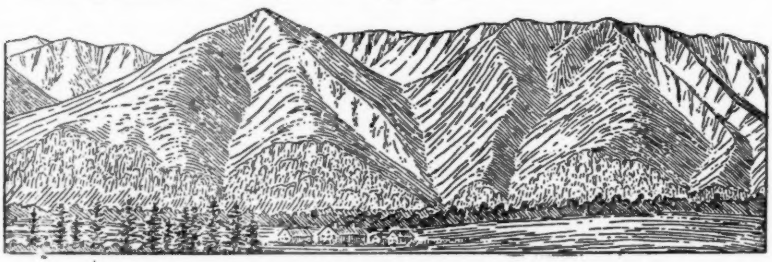

FIG. 4. Nearer view of truncated spur ends, Swan Range.

GLACIER NATIONAL PARK. *Features Due to Glacial Erosion.*—If any doubts are felt as to the truncation of the spur-ends at the western base of the Swan range on the ground that glaciers are incompetent to scour off mountain sides, the doubts should be dispeld by a visit to Glacier National park. Its features of glacial origin are of large scale, and of a kind not found in mountains of normal sculpture. They have been briefly described by Matthes[10] and Willis[11] and more fully by Campbell.[12] I had only a brief view of the district about Lake McDonald at the western entrance to the park, but the features there seen are so unlike those of mountains that have not been glaciated, they are so impossible of production by the processes of normal erosion, and they are so precisely of the kind that glaciers would produce if they had erosiv power, that they can admit of only one interpretation. Among the most manifest of these features are:—the broad trough of Lake McDonald, with its comparativly smooth, concave sides; the sharpend ridges and peaks which rise between broadly opend valley-troughs; the cirques hanging above side-valley troughs, which in turn

[10] F. E. Matthes, The Alps of Montana, Appalachia, X, 1904, pp. 255-76.

[11] B. Willis, Stratigraphy and Structure, Lewis and Livingston Ranges, Montana, *Bull. Geol. Soc. Amer.*, XIII, 1902, pp. 305-352.

[12] M. R. Campbell, The Glacier National Park, *Bull.* 600, *U. S. Geol. Surv.*

hang above larger and more deepend main-valley troughs. In mountains of normal erosion, broad valleys are associated with round crested and well dissected ridges; the occurrence of sharp ridges from which smooth concave slopes descend into broad troughs demands an agency which can have broadend the troughs rapidly enough to undercut the ridge sides and steepen their crests by sapping. Normally eroded broad valleys are joind at grade by open side-valleys; but the great troughs of the park have walls that are almost unbroken for miles together, and when breaks occur, they are not cut down to the level of the trough floor but remain "hanging" above it. Such forms demand an agency that can have occupied the whole breadth of the troughs and scourd their sides longitudinally.

The sharpend ridge crests above the level of glaciation are formd by the intersection of spatulate ravine heads, which widen upward and narrow downward as steep-pitching spur facets advance between them; the spur facets themselves as they widen are slightly but sharply incised by steep-pitching shallow ravines, but as the spur facets and the ravines descend to the level of glacial longitudinal scouring, their salient and reentrant forms weaken, until they are almost lost in the smooth trough sides. Rock structure is abundantly reveald and joints exercise much control in determining details of crest and summit forms, but the course of the steep ravines seems more guided by gravity than by rock structure. The trough sides show the initiation of Postglacial down-slope ravines; a well smoothd trough side next north of the northeast end of Lake McDonald is marked by down-slope "paths" thru strips of forest; the paths are somewhat concave in cross section in their upper part, as if scourd by snow slides; they are increasingly trenchd in their lower part, as if cut by streams. Near the forward-curving base several paths turn aside at a moderate angle from the direct line of descent, as if now avoiding cones of detritus previously formd.

THE FLATHEAD BASIN. *The Flathead Mountains West of the Flathead Plain.*—No local name could be learned for the low mountains, composed of indurated, east-dipping quartzites or sandstones as far as I saw them, which lie west of the Flathead plain and its lake, south of Kalispell; but they belong in a large group to which the name, Flathead mountains, is here given. They rise gradually in maturely dissected or subdued forms, which appear to be of normal origin in the higher western part of the mass, but which bear evident marks of subrecent glaciation along their irregular border, where the spurs advancing between reentrants of variable size consist of small-textured hills and hollows with countless scourd ledges and pluckt cliffs, as well as fluted channels suggestive of the direction of ice motion.

The eastward decrease of height in these mountains is at a much gentler angle than the eastward dip of the strata, and this suggests that the general profile of the mass results from the gentle eastward tilting of an old-mountain lowland or peneplain, so that the elevated part of the peneplain forms the second-cycle mountains of today, and the deprest part descends into the Flathead depression; but the dissection of the tilted mass is now so far advanced in its exposed part that no slanting tabular surfaces remain to attest former peneplanation; nor is anything known to me regarding a scarp or warp by which the uplifted area is limited on the west.

On the northwest of Kalispell, an open embayment enters the low mountains; and here the Great Northern railway originally made its way to the middle of the bent transverse valley of Kootenai river; but this line has been abandond beyond Kalispell in favor of the northern dêtour of lower grade, above mentiond. The embayment bears the marks of invasion by a small western branch of the Kootenai-Flathead glacier in abundant drift deposits on its floor and in hill-slope scouring along its southern side at least; the northern side was not seen. A small southward reentrant of the embayment contains three lakelets in ascending order, of which the upper or Foy's lake is the largest. All three seem to be shut in by morainic bars. A narrow, flat-floord channel leads southward from the highest lake thru the hills to a still narrower rock-walld gorge, which I took to mark the temporary, constraind course of the outlet of a proglacial lake in the western embayment. If this be correct, similar gorges should occur at higher levels, corresponding to greater overlaps of the constraining glacier on the eastward slope of the low mountains.

Along the western border of the Flathead plain from Kalispell to Somers, and along the western shore of Flathead lake south of Somers, the scourd and pluckt, clift and channeld spurs and hills at the base of the mountains, irregularly advancing into the plain and the lake and gradually disappearing beneath them, are in strong contrast to the evenly truncated spurs of the much higher and steeper Galton range east of the broad depression, and of the higher and steeper Mission range in the southern part of the depression. They give a characteristically irregular shore line to the lake. Near its southern end one of the spurs is prolongd across the lake basin in a series of low, well scourd and pluckt islands. The small-textured irregular features of the spurs and hills here described, taken with their scourd and pluckt, clift and channeld forms, may I believe be accepted as evidence of glacial action, even if striated rock surfaces are not everywhere found. The small-textured features are altogether unlike the systematic soil-coverd slopes of normally dissected spurs and hills of larger texture, such as prevail in the Piedmont belt of Virginia and

the Carolinas; but they are somewhat like the irregularly rugged hills of the deglaciated New Jersey highlands, which as Vermeule long ago pointed out are strongly contrasted with the smoother forms of the highlands south of the terminal moraine; and they correspond well with the irregular hills that I have seen in deglaciated areas of Central France[13] and of North Wales.[14] They are on the other hand distinctly unlike the irregular, small-textured forms of arid erosion, which present minute fretwork with many sharp angles that are wanting in the scourd and pluckt forms of deglaciated hills.

The contrast above mentiond between the smoothly truncated spur ends of the high Swan and Mission ranges on the east and the irregularly scourd spurs and hills of the unnamd low mountains west of the Flathead trough is probably due on the one hand to the steeper preglacial slope of the high ranges, in which the now precipitously truncated spur ends testify to strong longitudinal scouring along the

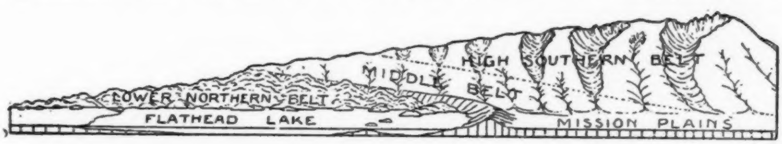

FIG. 5. Diagram of Mission Range, looking East.

side of the great glacial lobe; and on the other hand to the gentler preglacial slope of the low mountains, in which the rugged hills testify to scouring by an overlapping glacial lobe for a mile or more of breadth.

The Mission Range.—This well defined meridianal range takes its name from the long-establisht Catholic mission of St. Ignatius, west of its southern end. It appears to be composed of the same indurated and deformd sandstones that are so widespread in western Montana; and it may be conceivd as a fault block, some fifty miles in length, broken from the old-mountain peneplain of which so many traces are found hereabouts, uplifted with a gradual southward rise to an altitude of about 10,000 feet near its abrupt southern end in the southern part of the Flathead depression. As seen from the west its submaturely carvd mass, summarized in Fig. 5, shows recent sculpturing by local glaciers in the higher valleys of its lofty southern belt, and heavy scouring by the overlapping end of the Kootenai-Flathead glacier in its low northern belt. Between these two parts is an oblique intermediate belt, of purely normal sculpture. This belt lies beneath the

[13] Glacial Erosion in France, Switzerland and Norway, *Proc. Bost. Soc. Nat. Hist.*, xxix, 1900, pp. 273-322.

[14] Glacial Erosion in North Wales. *Quart. Journ. Geol. Soc.*, lxv, 1909, pp. 281-350.

high southern belt where features of glacial and of normal sculpture alternate, and above the low northern belt, in which large textured normal features are worn into small textured ledges of glacial scouring. No other mountain range is known to me which exhibits so systematic a combination of these three kinds of forms. For that reason I have given it a fuller description elsewhere.[15]

The Mission range provides desired confirmation for the explanations already offerd in describing the arbitrarily irregular, small textured hills and knobs, channels and hollows along the border of the low mountains west of the Flathead trough, and for the truncated spur ends of the Swan range on the east; for the lower northern slope of the Mission range, where it bears the marks of overriding by the great glacial lobe, exhibits a confusion of small textured forms, most irregularly commingled. The western base of the range, which bears the marks of strong lateral ice-scouring, shows a succession of roughly truncated spur ends alternating with side moraines in the interspur ravines, both of systematically decreasing altitude southward to the point where the superb Polson terminal moraine swings away past the mountain base and bars the adjoining lake basin. Farther south the spurs dwindle away in the piedmont plain, as they did in the southern extension of the Swan range. The contrast between the strikingly irregular western shore of Flathead lake and its relatively simple eastern shoreline is evidently due to the occurrence of small-textured hills and knobs on a glacially scourd surface of moderate declivity on one side of the basin, and of systematically truncated spur ends, worn back to an almost continuous mountain base of steep slope, on the other. The repetition here of the same orderly relation that was observd along the base of the Swan range between decreasing spur-end truncation and a curvd morainic belt tangent to the range base, makes it highly probable that the spur-end facets in both ranges are due to glacial erosion and not to faulting. The bearing of these features on the general problem of sublacustrin glacial erosion is stated at the close of this article. It is interesting to note that in both localities the glacial records change from erosional forms to morainic deposits as advance is made southward from a constraining mountain border to an open plain. The considerable height to which the ice-scourd knobs seem to occur on the northern end of the Mission range makes it probable that a moraine of the eastern ice lobe, into which the great Kootenai-Flathead glacier was divided by this range, should be found several miles up Swan river valley on the east, corresponding to the Polson moraine in the broader basin on the west. Whether

[15] The Mission Range, Montana, *Proc. Nat. Acad. Sci.*, I, 1915, pp. 626-628; also *Geog. Rev.*, II, 1916, pp. 267-288.

Swan lake lies inside or outside of such a moraine I could not learn; but a resident of the district told me that the "pot-hole country," as he called the morainic area, extended into Swan river valley.

Flathead Plain and Lake.—The extensiv Flathead trough, measuring from 12 to 30 miles in width by 110 in length, is smoothly aggraded over most of its extent, both north and south of Flathead lake, by gravels and sands, presumably representing the outwash of the retreating Kootenai-Flathead glacier. The surface has in general the form of a plain, at an altitude of from 2,900 to 3,100 feet; but it is varied by morainic hills in the south, by terraces of small relief along the stream courses, and by occasional basins holding lakes, mostly of small size. The northernmost lake that I saw in this plain was Whitefish, a few miles in length; it appeared to occupy a basin kept free from gravels by an isolated ice-mass. Flathead lake, on the other hand, seems to be the as yet unfilld part of the Flathead trough, elsewhere aggraded. This lake, already described as 27 miles long and from 6 to 15 wide, is reputed to have a depth of several hundred feet; its surface is at an altitude of about 2,900 feet. Flathead and Swan rivers are both forming delta plains at the north end of the lake: Swan river is peculiar in approaching the lake thru a gorge in the low northern end of the Mission range, as if it had been superposed there from a temporary course on the retreating ice sheet; its preglacial course was pretty surely farther north. The broad Flathead trough, now aggraded in the Flathead plain, appears to be an area of down-faulting or down-warping, just as the neighboring mountains are areas of uplift of a preexistent worn-down, old-mountain region. The trough presumably contains stratified deposits washt in from the mountains, beneath the fluvio-glacial gravels and sands that now form its surface plain; but I saw nothing of the underlying strata. Whatever their original thickness, it is probable that they were somewhat eroded by the invading glacier.

The Polson and Mission Moraines.—The Polson moraine, which limits Flathead Lake on the south, is a well defined feature of the Flathead trough. It forms a hilly belt from one to three miles in width, stretching with pronounced southward convexity for eight or ten miles westward from the Mission range; it rises from 300 to 500 feet over the lake, and is sparsely strewn with boulders up to ten feet in diameter. On the east, its northward continuation may be traced in a remarkable series of embankments which bar the normal valleys in the middle part of the Mission range at higher and higher levels, corresponding roughly to the tops of the spur-end facets, until they reach the northward descent of the range crest. The slope of

the ice lobe may be measured by these embankments; it is about 1,000 feet in fifteen or twenty miles. As may be inferd from the account of my route given in the intinerary above, the embankments were seen only from a passing steamer at a distance of from one to three or five miles, yet their form and their arrangement and especially their relation to the Polson moraine were such that I felt no doubt as to their origin. On the west where the country is more open, the northward turn of the moraine could not be surely traced from my points of view. Lower Flathead river, as the outlet of the lake may be called, escapes thru a gap in the southwest part of the moraine, where gray silts are exposed in the banks.

West of the Mission range the Flathead plain continues for twenty or twenty-five miles south of the Polson moraine, and there it may be called the Mission plain; it attains a width of fifteen or twenty miles owing to the withdrawal of the hills on the west. Part of the plain here has a fine brown soil, probably lake silts colored by humus. Gray silts, with local accumulations of gravel, were here cut in the ditches of the Flathead irrigation project of the Reclamation Service. The silts are probably the sediments of Lake Missoula into which the gravels may have been ice-rafted. Farther on, the plain passes into the broad Mission moraine of which a brief account has been given by Elrod.[16] It is of faint relief, dimpled with hundreds of small hollows holding pools after wet weather, and dotted with thousands of boulders. The distance between the Polson and Mission moraines is about twenty miles. The Mission moraine is but little if any higher than the plain to the north of it, but it descends 100 or 200 feet to a lower plain on the south by a slope which seemd to be convex in plan. The lower plain is limited on the south by a range of subdued hills of deformd quartzitic strata, beyond which is the valley of Jocko creek, followd by the Northern Pacific railway. Flathead river turns westward from the basin plain and then again southward thru the hills to the point where, receiving Jocko creek—the town of Dixon is at the junction—it tends to follow the long northwestward valley that farther on is entered by Clark fork.

Agriculture on the Flathead Plains.—The plains of the Flathead trough, like many other intermont basin plains in Montana, have attracted a thriving agricultural population, which is destind to increase, especially in the areas served by the irrigation ditches of the Flathead project, as constructed or pland by the Reclamation Service. This project provides "for the irrigation of about 152,000

[16] M. F. Elrod, The Physiography of the Flathead Region, Bull. Univ. Montana, *Biol. Ser.*, 1903, pp. 197-203.

acres of land in various parts of what was the Flathead Indian reservation, water being diverted from creeks and rivers rising in the Mission mountains and conducted by canals directly to the land and to reservoirs for storage of floods. The gravity supply will be supplemented when necessary by pumping from Flathead lake. The area of the drainage basin is approximately 8,000 square miles." Roads here follow mile-square section lines, except where they are constraind to turn in crossing the bordering hills and ridges. A branch from the Great Northern railway, which crosses the northern part of the plains, extends to Kalispell, the chief town of the district, and to Sommers at the northwestern angle of Flathead lake; Somers and Polson are connected by steamboat service on the lake; from Polson a quick crossing may be made by automobile southward to Ravalli on the Northern Pacific railway. The mountains afford an abundant supply of timber and summer pasture. The Montana National Bison range, enclosed by a strong fence, occupies about 30 square miles on the hills between the south end of the basin and the valley of Jocko creek.

THE KOOTENAI-PEND OREILLE DEPRESSION. *The Trough of Kootenai Lake.*—We next pass to the Purcell trench in the Kootenai-Pend Oreille region, and begin the account of it at the northernmost point visited on my excursion. Kootenai lake, beginning 18 miles north of the international boundary, occupies the deepest part of one of several almost mature glacial troughs, overdeepend by the great trunk glacier of a number of recently extinct glacial systems. The troughs follow the main valleys of the Selkirk mountains, which as a whole are submaturely dissected to strong relief of prevailingly insequent pattern. The lake is 65 miles long north and south and two or three miles wide; it is said to have been sounded to a depth of 800 feet; its surface stands at 1,760 feet above sea level, while the adjoining mountainous highland has summits that reach elevations of 8,000 feet and more. After Kootenai river enters the trough from the east, it turns sharply to the north—Bonners Ferry lies at the elbow—and flows to the lake over a delta plain some 30 miles in length. The lower Kootenai, which forms the lake outlet westward to the Columbia river, escapes by a lateral distributary of the main trough, into which a narrow and comparatively shallow arm of the lake projects a few miles from the lake mid-length. Nelson lies where the river begins.

Glacial Origin of the Lake Trough.—The river and lake trough is described as almost mature because, altho the adjoining mountain spurs are strongly truncated, the trough sides still preserve some of

the crags and knobs and promontories of glacial immaturity. This appeard to be particularly the case in the north end of the basin where the shore lines, as seen from the middle of the lake, seemd to be more varied by rocky salients than farther south; a well-scourd rocky island rises near the middle of the lake. Two bays indent the lake shores; one is near the middle of its eastern side; the other is of more irregular pattern on the western side. In the southern half of the basin the unconsumed knobs and ledges are smaller, and the scourd, pluckt and channeld outlines of their rounded, small-textured forms express very emphatically the advanced stage of the severe longitudinal scouring to which they are due. Viewd in the larger way, the sides of this part of the trough rise in concave slopes to slanting triangular facets of unlike size which truncate adjacent mountain spurs and leave hanging between them the shortend or betrunkt upper parts of numerous normal valleys; but some of the high-level side openings of the main trough are hanging glacial troughs of well developed catenary cross-section; a fine example of this kind is seen west of the lake near the entrance of Kootenai river. Slightly incised, postglacial chasms descend from the normal hanging valleys and side troughs toward the lake, where small gravel deltas are forming. The high-level spur facets are remarkably well alignd, so that they unite downward below the valley notches in the longitudinally continuous, concave trough-sides, which give the southern half of the lake a comparatively simple outline. The shoreline is smoothest where it follows patches of drift or growing gravel deltas; its irregularities are numerous but of small texture where it contours along bare rock ledges.

Trough-Side Clefts.—The rocky slopes of the trough side often show oblique clefts, which intersect so as to outline an irregular network with lozenge-shaped meshes, and thus indicate the influence of lines of weakness such as are determind by master joints or faults in guiding the processes of glacial scouring and plucking. Similar forms are to be seen on the deglaciated trough sides of Lake Como. The oblique network of joint clefts thus produced further indicates, to my reading, that joints and fissures are not as a rule potent factors in the guidance of valley erosion, because the branch work of valley lines on a mountain side, where each line follows a direction of maximum slope, is essentially unlike the irregular criss-cross network of joint clefts, the members of which usually depart from the direction of maximum slope. Joints and fissures thus appear to be important in guiding the scouring and plucking action of glacial erosion, much in the same way that they are important in guiding the normal weathering and erosion of clefts in steep and bare rock surfaces, from which

the rock waste is removed about as fast as it is detached; but as soon as a surface that is attackt by normal weathering and erosion is worn back to a gentle slope, so that rock waste begins to cloak it, and whenever a stream course is curved so that lateral erosion is effectiv, the importance of erosion along joints and fissures becomes subordinate to the development of stream-guided valley lines. From this time on, the stream-guided lines become dominant with but little regard to joints and small faults. It is of course true that a master fault may be borderd by so wide a belt of brecciated rock, that a subsequent valley will be developd along it; but it seems to be equally true that, in a jointed or fissured rock mass, such as that of the mountains which enclose the Kootenai trough, the ordinary joints or fissures will not suffice to guide the gentler process of normal erosion, by which branching normal valleys are formd, even tho they have guided glacial scouring.

Hanging Lateral Valleys.—The smaller hanging valleys of normal erosion are abundant, characteristic, and pleasing elements of the trough sides at high levels. They open upwards in half-funnel forms between the normally graded side slopes of the truncated spurs. The larger normal valleys are cut down to a lower level, but seldom so low as the lake shore; they subdivide headward into the mountains in the pleasingly irregular fashion that characterizes insequent drainage. But besides the hanging normal valleys of V-shaped cross section, there are, as above noted, several hanging lateral glacial troughs, with catenary cross-section; and these are of two kinds, incoming or tributary, and outgoing or distributary. Some of the smaller ones of the first kind hang well above the lake surface; other larger ones are cut down nearly as low as the lake. The single example of a hanging distributary is the one above mentiond that opens to the west near the middle of the trough; the distributary trough is somewhat deeper than the lake surface at its beginning and is therefore slightly drownd in the narrow, river-like western arm of the lake. Its depth decreases westward to a flat col, across which the lake arm gives forth the lake outlet.

Evidently a relativly small volume of ice turnd west here, and the larger volume went on south; otherwise, the western arm should be the deep main trough and the southern trough should be a shallow distributary arm. The town of Nelson lies where the lake-arm becomes a river; a little farther on the river descends in falls on its way to the Arrow lakes and the deeper trough of the Columbia; hence the glacial distributary that here left the Kootenai glacier connected it, in the net-work fashion that is characteristic of ice drainage, with the Columbia glacier. Two fine incoming glacial troughs hang well

above the west-arm distributary in its southern side, just as it hangs well above the main lake bottom; and in this two-story discordance is to be found strong evidence of great overdeepening in the main lake trough.

The Nelson Distributary Trough.—As only a small part of the west-arm or Nelson distributary is submerged where it leaves the main lake, almost its entire catenary cross section is visible: its steepest slopes, although steeper than the sides of the normally graded mountains that rise above them, probably do not exceed 30° or 35°. Hence the trough has little resemblance to the letter U, with which some glacial troughs, like those of Lauterbrunnen in the Alps and parts of the Sogne fiord in Norway, may be compared. The difference of origin between true U-troughs and those of more open catenary form may perhaps be explaind by supposing that the former represent a youthful stage of active deepening by a rapidly moving and strongly eroding glacier, preparatory to a later stage of widening; while the latter exhibit a mature stage of gradual widening, whether preceded by an active deepening or not.

The catenary cross section of the west-arm distributary trough warrants the inference of a similar form for the main trough. If a cross-section curve is begun in the higher slopes of the trough sides, which descend at angles of 30° or 25°, and is continued beneath the lake surface which is three or four miles in width, the depth of the rock trough they indicate will be significantly greater than the reported depth of 800 feet for the lake bottom. The lake may be somewhat shoald by glacial drift or outwasht deposits.

It may be well to point out that the production of such a lake as Kootenai by the warping of a normal, maturely widend preglacial valley is, as Wallace pointed out years ago, an impossibility. A maturely widend valley of normal erosion must have all its side valleys cut down so deep that their streams unite with the main stream at accordant levels; and if such a valley were warpt, so as to hold a lake, the lake shoreline would necessarily possess as many side bays as there are side valleys to be drownd: but Kootenai lake has very few side bays; and such bays as it possesses are probably submerged hanging lateral troughs.

Lakes Kootenai and Maggiore.—Except for the absence of all signs of human occupation, such as villages, fields, roads, paths, and terraces, and except for differences of vegetation, the mountain sides of Kootenai trough along its southern half present many systematic resemblances to the mountain sides of Lake Maggiore in the Italian Alps, as in all such great glacial troughs, one may note the prevalence

of simple shorelines, with few promontories and fewer embayments; the continuity and the simple form of the slanting trough sides, cut in chasms only where streams descend from the hanging valleys of normal form, and deeply breachd only at the entrance of hanging glacial troughs; the occurrence of open lake arms in submerged tributary or distributary troughs, the broad lake arm in the hanging tributary trough of Lake Maggiore, corresponding to the narrower lake arm in the hanging distributary trough of Kootenai; the concave ascent of the trough-side slopes into triangular facets by which the mountain spurs are so evenly truncated; the occurrence of occasional unconsumed knobs and sills on the trough-side slopes, alternating with occasional sheets of drift, and the more common occurrence of well scourd rock ledges with gently convex profiles on lines parallel to the lake shore; the scourd-out network of oblique clefts on the trough sides, as if disclosing the master joints or fissures of the mountain mass; the normal forms of the hanging lateral valleys between the truncated spurs; the foaming torrents that cascade from the hanging valleys down the trough-sides; and the trifling amount of Postglacial change, limited chiefly to the torrent-cut chasms beneath the hanging valleys and to the small deltas at the foot of the clefts.

From Kootenai Lake to Lake Pend Oreille.—As one travels southward along the delta-plain of the Kootenai trough, the trough-side wall continues to limit the mountains on the west, until as one ascends over a flat drift divide to the broad plain north of Lake Pend Oreille, features of glacial origin in the enclosing mountains are for a time of less and less distinctness. South of the international boundary as well as north, the Canadian name, Selkirk mountains, may be applied to the mountain mass on the west. Several of the higher summits, above 7,000 feet, some miles west of the trough, show sharpend summits between the widend, almost confluent floors of adjacent cirques; it is to be presumed that glacial troughs descend from such cirques. The summits of less altitude are of dome-like form and seem to be remnants of an uplifted mass of moderate relief, never smooth enough to be called a peneplain, and now submaturely incised by normal valleys.

The eastern base line of the mountain mass all along the western side of the great trough is singularly simple, being without spurs that stretch forward into the trough plain, and almost without re-entrants that indent the mountain border. Many maturely open normal valleys terminate in hanging fashion on the trough side or mountain face, and their streams descend the lower slope in narrow chasms that hardly interrupt the continuity of the pluckt, scourd, and cleft mountain slope; but glaciated side valleys are not numerous.

In the middle part of the Kootenai-Pend Oreille depression, where its breadth is increased by the recession of the mountains on the east of it, as stated below, the mountain border on the west may perhaps be interpreted as a north-south fault-line scarp, maturely dissected aloft and simplified by glacial scouring on its lower slopes; but in the absence of information regarding the structure of the district this suggestion cannot now be tested.

The Purcell mountains on the east side of the Kootenai trough recede eastward about midway from the lake head to the Bonner elbow, and thus a depression 12 or 15 miles in width is opend. The village of Creston is at the northern limit of the widend depression, which is well defined; the southern limit is vaguely markt beyond Bonners Ferry. The recession begins where a large glaciated trough, that of Goat river, comes in from the highlands on the northeast, and it is conceivable that the width of the depression is due to the junction of this trough with the greater one. The eastern mountain wall farther southward is at first very bold, rising to a plateau-like highland and giving suggestion of horizontal structure in its high cliffs above great talus slopes; a fine hanging valley opens at mid-height in the cliffs. The southern extension of this mountain mass is interrupted by the east-west transverse valley by which Kootenai river flows from its eastern to its western trough at Bonners Ferry, and the name, Purcell range, is limited to the area north of this valley. The name, Cabinet range, is given to the mountains following on the south. They were not well seen on my trip, but occasional views of their flanks showd abundant signs of ice scouring.

The Creston Terrace.—The eastern half of the broadend Kootenai depression from Creston to Bonners Ferry is occupied by an extensiv terrace at an altitude of 2,200 feet, here called the Creston terrace, of which there is no sign farther north along either side of the lake trough. The terrace deposits perhaps result from the aggradation of the space evacuated by the tributary Goat-river glacier, while the main Kootenai glacier still extended farther south. Goat river, on emerging from its mature mountain trough at the northeastern angle of the depression and cutting thru the terrace beds, is locally superposed on the underlying rocks and has there cut a deep and narrow chasm, which is spand by a high bridge on the Crows Nest line of the Canadian Pacific railway; farther down stream the river has eroded a fairly open valley in the terrace.

A large tributary of the Kootenai glacier must have come down Goat-river trough, as the trough sides are spurless and maturely smoothd in their lower slopes, and notcht by hanging valleys in their upper slopes. The Crows Nest line enters the Goat-river trough

about 25 miles from Creston by a hanging branch trough from the east, and slants down the drift-patcht slope of the southern trough wall beneath the level of its lateral hanging valleys. When the terrace in the Kootenai depression is reacht, the railway crosses its high surface westward to the slope by which it falls off to the Kootenai delta plain; there Creston stands; then turning northward, the railway slants along the side slope of the Kootenai trough, again beneath the level of several hanging valleys, and descends to the level of the Kootenai delta plain; thus for the second time avoiding the detours or viaducts that would be necessitated in passing along the side wall of a maturely open normal valley, in which the side valleys would be cut down to the main valley bottom.

The Kootenai Delta Plain.—In the stretch of 36 miles from the Bonner elbow of the Kootenai to Kootenai lake, the river flows northward through a smooth alluvial flood plain and delta of about the same width as the lake. On the west the mountains, as above described, rise from the plain just as they rise from the lake farther north; and so they rise on the east also from that part of the flood plain which lies between the head of the lake and the Creston angle where the eastern recession of the mountains begins. The rest of the eastern side of the plain is limited by the slope of the high terrace. The base of the terrace seems to be defined by occasional outcropping ledges of granite, that have defended the surviving part of the terrace from being undercut by the swinging river. It does not seem probable, however, that the terrace ever extended completely across the whole trough, for in that case remnants of it should be seen along the western trough-side where none were noted.

The delta plain offers extensiv meadows for pasture, but is subject to floods that have discouraged agriculture. It is proposed to submerge a good part of the plain by raising the level of Kootenai lake by a dam across its outlet at the rapids a short distance below Nelson on the western lake-arm; but the raisd lake would extend across the international boundary, and the legal questions involvd in this project have causd delay.

The Drift Divide Between Kootenai and Pend Oreille Lakes.—Next southwest of Bonners Ferry, an abandond meander of the Kootenai is mapt as Mirror Lake. About midway from Bonners Ferry to Lake Pend Oreille, the Purcell depression, here called the Kootenai trough, is narrowd to four and even to two miles; it is here occupied by drift and silts, increasing in altitude southward, in which a small stream has accomplisht a moderate amount of terracing. The drift divide at the head of this stream is of somewhat irregular form,

and is very likely formd in good measure of morainic deposits. It has an altitude of 2,253 feet where crost by the Great Northern railway at Elmira station, and there separates the delta plain of the Kootenai, which slopes gently northward to Kootenai lake, 1,760 feet in altitude, as above described, from a higher plain that slopes gently southward for ten miles to Lake Pend Oreille, 2,051 feet in altitude. This higher plain is occasionally interrupted by rocky knobs, and is slightly dissected by narrow valleys, which show bedded sands or clays. The large extent of the plain suggests that the Kootenai-Pend Oreille glacier stood for a considerable time near the Elmira divide; and it is possible that the moraine there corresponds in time with the Polson moraine of the Kootenai-Flathead glacier. This possibility will be further considerd in the latest division of the essay. The town of Sandpoint lies at the southern margin of the plain where an arm of the lake turns westward to its outlet by Lower Clark fork. Here the Northern Pacific railway, that has followd down the valley of Upper Clark fork, yet to be described, and rounded the northern shore of the lake past Sandpoint, crosses the western arm on trestle work; the Great Northern railway which has come southward from the Bonners elbow of Kootenai river, follows the outlet and crosses it a few miles west of the lake. A branch of the Canadian Pacific turns from the Crows Nest line before it enters Goat-river trough, and also passes by Bonners Ferry and Sandpoint on the way to Spokane. Before the formation of the Elmira-Sandpoint plain the lake must have been much longer than it is now. The level of this plain is so nearly the same as that of the high silt terrace east of Kootenai delta plain, that both were probably formd in the same proglacial lake—a large expansion of Lake Pend Oreille—when the westward discharge of Kootenai lake and river past Nelson was still obstructed by ice. The delta plain of the Kootenai is at a lower level and evidently of later origin.

The Transverse Valley of Kootenai River.—The eastern half of the bent transverse valley by which Kootenai river crosses the southern extension of the Selkirk Mountains from the Kootenai-Flathead depression on the east to the Kootenai-Pend Oreille depression on the west was traversd by train on the Great Northern railway after dark; the following notes refer to the western half, from Libby (2,205′) in the midst of the mountains to Bonners Ferry (1,761′). At Libbey there is an open depression, in part occupied by heavy deposits of white silts and terraced by a stream from the southeast: it was by a pass at the head of this stream that the original location of the Great Northern railway came from Kalispell to Libby. Southwest of Libby, glimpses were caught of a group of high summits in

the Cabinet mountains with Alpine forms, as if strongly sculptured by former glaciers. Not far down the valley from Libbey four tributary valleys enter from the north; the first and fourth join the main valley at accordant levels as normal tributaries; the second and third join at discordant levels as hanging tributaries; and hereabouts the main valley has a rather well developd trough form, scourd in bedded rocks that dip upstream.

Kootenai Falls are a little farther down stream; there the river suddenly changes its habit from that of a wide, smoothly flowing current on the trough floor, to that of a narrow and impetuous torrent in a ragged gorge that is incised beneath the trough floor. The falls at the point of change may be 20 or 30 feet in height, but a rapid descent is continued for some distance down stream. Remnants of the trough floor are seen in the form of ragged rock benches on either side of the river for half a mile or more below the falls: then the valley widens, as if the rocks were weaker. In a valley of normal erosion it would be difficult if not impossible to account for these singular features without postulating a recent warping of a formerly mature valley, in such manner that the river should be locally revived to deeper erosion; but in a deglaciated valley, which evidently owes its trough-like form as well as its depth below some of its tributaries to glacial erosion, it is legitimate to assume that the scourd floor of the trough departs from the continuous down grade that a river would produce, and that a river flowing thru such a trough would incise a gorge wherever the rock floor has a sufficient slope.

On approaching Bonners Ferry, the river is confined in a narrow gorge on the south of the high terrace that there occupies the broadend Kootenai trough: the gorge appears to be the result of superposition thru the terrace deposits, which probably bury the former river valley. The gorge is well seen from the Canadian Pacific line, which skirts the edge of the high terrace in ascending northeastward from Bonners Ferry.

THE PEND-OREILLE-SPOKANE REGION. *The Distributaries of the Kootenai-Pend Oreille Glacier.*—The irregular distribution of mountains and valleys in the region into which the great Kootenai-Pend Oreille glacier advanced—here called the Pend Oreille-Spokane region—resulted in its subdivision there into several out-going branches or distributaries. A distributary crept down the valley of Lower Clark fork for some twenty-five miles, and supplied a large volume of washt drift, remnants of which now form extensiv terraces; this branch seems to have moved slowly around or over the isolated mountains that obstructed its course; it has not left conspicuous marks of its passage. A southwestern distributary advanced an unde-

termind distance between detacht ridges and knobs. A southern distributary continued some 20 miles, overdeepend the trough of Lake Pend Oreille and supplied from its extremity, with the aid of the southwestern distributary, the vast volume of gravel and sand that forms an outwash plain as far as Spokane. The southeastern distributary ascended the valley of Upper Clark fork for an undetermind distance, and with the aid of local glaciers greatly modified the form of the valley sides by erosion. The troughd valley was afterwards encumberd by large volumes of morainic and outwasht deposits during the waning of the invading glaciers.

It was the work of the southeastern distributary of the great Kootenai-Pend Oreille glacier and of local glaciers farther up the Clark fork valley that formd the central object of my excursion. Moreover it appears to have been this distributary of the great glacier which, separating from the southern distributary where the ice surface had an altitude of somewhat more than 4,000 feet, bard the waters of Lake Missoula in the branch valleys of Upper Clark fork. Singularly enough it seems to have been beneath the waters of this lake that the ice in the Upper Clark fork valley did its highly significant erosiv work, as will be further set forth below.

The Southwestern Distributaries of the Kootenai-Pend Oreille Glacier.—The description of these glacial distributaries is difficult from the irregularity of their courses and from the lack of names for the isolated mountains by which they were subdivided, to say nothing of the shortness of the time that I could give to their examination. Fig. 1 serves to show the general distribution of the smaller mountain masses between the strong range (4,500′) which extends northward from the Chilco mass (5,625′) along the west side of Lake Pend Oreille, the still stronger Selkirk Mountains on the northwest (6,700′), and the Mt. Carlton (5,508′) outpost mass (C. Fig. 1) on the southwest. The names Curtis, Huckleberry and Algoma (S., H., A., Fig. 1), are here adopted for smaller unnamed mountains of intermediate position, from the names given on the maps for local features near them.

Soon after leaving Sandpoint on the way down Lower Clark fork valley, glacial scouring, well assured though not so strong as north of Sandpoint, was seen along the southeastern flanks of the Selkirk Mountains nearly to their southernmost extremity; drift seemd to be packt into their embayments; the mountain tops and the higher slopes have normal forms; the valley bottom is occupied with stratified clays. Ice-scourd slopes were noted on the northern flanks of Algoma and Huckleberry mountains, southeast of the river. Hoodoo valley, between Curtis and Huckleberry mountains, was not visited;

it is followd by the Canadian Pacific branch line, known as the Spokane and International railway, and from the details of the topographic maps it appears to have been enterd southward by a branch of the western glacial distributary here considerd; for the marshy depression (2,200′) on its east side, and the marshy basin high (3,000′) on the east flank of the Curtis mass both suggest glacial disturbance of normal drainage. More significant still is the heavy tabular body of morainic drift (2,500′) with large boulders, east of the Mt. Carlton mass, probably to be associated with the southwestern glacial distributary, as will be further described in a section concerning the Lone Mountain gravel mesa. The peculiar, river-like Hoodoo lake will be referd to in the section on the outwasht gravels of the southern glacial arm. A rather small branch of the southwestern glacial distributary may have past between the West Pend Oreille range and the Huckleberry mass, where Cocolalla lake now lies; the Northern Pacific railway follows this depression, but it was after dark when I ran through it.

Lower Clark fork turns northwest after passing between the southern end of the Selkirk Mountains and Curtis mountain. No signs of glacial action were there noted, but as the high terrace (2,300′) which seems to consist of outwash from the ice, does not begin for a few miles down the river, it is likely that a lobe of the ice advanced at least as far as the terrace head, altho marks of erosiv action are not there evident. The river has now cut down more than 200 feet into the high terrace, and is superposed near the terrace head on a rock ledge, in which it has cut three narrow notches; here are Albany falls, where the Great Northern railway crosses the river; two miles farther down stream, the town of Newport lies on the terrace which continues southward along the west flank of the Mt. Carlton mass, past which the railway runs on the way to Spokane. A singular feature here noted was that a head branch of Little Spokane river rises close to Newport and flows on its southward course thru a narrow, rock-walld gorge with much fresh talus, in part occupied by a long narrow lake. This had the appearance of being the work of Clark fork or of a distributary of that river, temporarily deflected southwestward during the aggradation of its high terrace. If so, the return of the river to the northwestward course below Newport is probably to be explaind by the easier trenching of the terrace deposits in that direction than southward. Much field study remains to be done here.

Lake Pend Oreille and its Glacier.—The heavy deposits of clays and silts which form the broad plain (21-2290′) north of Lake Pend Oreille (2051′) have a length of about ten miles; if they

were absent, the lake would probably drain northward into the trough excavated by the main body of the Kootenai-Pend Oreille glacier, for Kootenai lake is nearly 300 feet lower than Lake Pend Oreille. The western five-mile arm of the lake at its northern end may be associated with the western and southwestern distributaries of the glacier; the northern part of the lake, as far as the delta at the mouth of Upper Clark fork, may be regarded as the work of the undivided southern and southeastern glacial distributaries, before their separation; the curvd remainder of the trough, some twenty miles in length and two or three miles in width, is the work of the southern glacial distributary alone, and includes the finest part of the lake, as rated in terms of the bold mass of its mountain walls. A depth of 1,300 feet is said to have been measured near the middle of the lake by competent recorders. Unfortunately I saw the north end of the lake only near the close of a hazy afternoon, the southern end only from the moraine at its southwestern extremity, and the middle part not at all; hence certain details here following are taken from the Priest lake, Cataldo and Rathdrum topographic map-sheets.

Oversteepened Lake-Trough Walls.—The precipitous slopes of the trough sides, seen in the oversteepend mountain walls above the lake surface. are remarkably free from projecting spurs, and suggest a strong measure of vertical glacial erosion or overdeepening of the lake bottom, as well as of lateral erosion or oversteepening of the preglacial valley sides. The glacial erosion of the trough sides is especially striking in the somewhat amphitheatral mountain walls on the convex sides of the curvd lake. One of the steepest walls is next west of the entrance of Clark fork. Here the enclosing mountain mass, which is represented on the map as having abundant normally branching valleys and spurs on the non-glaciated slope south of its crest line (4,500′) where it appears to have been out of reach of the ice, presents on the north a smooth wall, without significant salient or reentrants, which descends 2,000 or 2,500 feet in a slope of about 35° to a simple shore line. High on this steep wall is the probable location of the outlet of Lake Missoula, as will be further stated in a later section. The first oversteepend concave wall is on the west side of the lake, a few miles farther south; here again a smoothd mountain side, 1,000 or 2,000 feet in height, descends to a simple shore line; but in the mid-length of this wall, where the crest height is 3,000 feet or a little less, the ice probably overflowd westward: on the opposit or eastern side of the lake the mountain slope is more dissected and less precipitous. The long curve of the lake on the southeast is enclosed by a well clift mountain side, except where the

two valleys of North and South Gold creeks enter from the east and south. To the north of these valleys, the ice-scourd walls are of moderate height, but their abrupt descent is in striking contrast to the normally carvd mountain slopes above them; a normal late-mature valley has here lost its lower part, and hangs some 1,500 feet over the lake bottom. The wall along the south end of the lake is remarkably simple for most of its length, and forms a well-matured trough-side; its height increases westward from the Gold creek valleys, and where the highest part of the enclosing slopes, beneath Bernard peak (5,200′) at the north end of Chilco mountain, is undercut, there is a precipitous descent of 2,500 feet to an exceptionally smooth shore line. Only a few hundred feet of the mountain top retain their normal slopes above the clift wall, and these are encroachd upon by activly retrogressiv ravines. West of Bernard peak, the ice-scourd wall rapidly decreases in height, but is maintaind as a well defined feature to the very extremity of the lake. The convex wall on the northwest side of the southern turn, culminating in Cape Horn peak, is well scourd, and at its sharpest turn is almost as steep for 1,500 feet above the lake as the concave wall.

Estimate of Glacial Overdeepening in Lake Pend Oreille.—It would be difficult to imagin a group of forms more convincingly demonstrativ of strong glacial erosion along a preglacial valley than these systematically steepend, spurless mountain walls, with normal forms and hanging side valleys above them and with a deep lake basin between them, all in a district where the mountains in general have subdued forms of moderate slope, with well graded branching spurs, separated by branching valleys of accordant junctions. The amount of deepening that the preglacial valley sufferd may be roughly estimated as follows:—At the southeastern curve of the lake shore, near its southern end, the valleys of North and South Gold creeks, above mentiond, enter from hills and mountains of apparently normal, late-mature forms; if these valleys were invaded by ice, the work done there must have been small. The valleys seemd, as well as I could judge from a point of sight to the west, to be about as deep as the lake surface; the village of Lake View lies at their mouth a little above the level of the lake. Now inasmuch as all the mountain forms hereabouts, outside of the glaciated areas, show normal forms of late mature, well subdued expression, it follows that these branch valleys from the east and south must have been, in preglacial times, about as deep as the larger valley that they joind in what is now the lake trough; and further, that as the lake is, according to recent soundings, 1,300 feet deep, 1,000 feet may be taken as a fair minimum measure of the amount of glacial overdeepening that the pre-

glacial valley has sufferd in its conversion into a glacial trough. The lateral erosion of the preglacial valley sides at the level of the lake surface must have been much more than 1,000 feet at several points.

It should be noted that altho the surface of Lake Pend Oreille (2,051′) is almost 300 feet above that of Kootenai lake (1,760′), the bottom of the southern lake (2,051-1,300 or 751′) is lower than the bottom of the northern lake (1,760-800′, or 960′), as far as present soundings go. It thus becomes all the more probable that the divide (2,250′) between Bonners Ferry and Lake Pend Oreille is bankt with morainic drift deposits of great thickness; otherwise the two lake troughs might be confluent.

The Moraine at the South End of Lake Pend Oreille.—The southwestern end of the lake is bard by a heavy moraine, and divided by a blunt morainic cusp into two bays, of which the southern one, borderd on its southern side by the ice-scourd wall above mentiond, is two and a half miles long without a local name, and the northern one, mapt as Squaw bay with the village of Bay View at its end, is a mile and a half long. A branch of the Spokane and International railway rounds the morainic hills and descends nearly to lake level at Bay View; limestone quarries are workt near-by, and cement quarries are opend in the southeastern wall of the lake. For several miles west of the lake end, heavy morainic deposits occupy what might otherwise be an open extension of the lake trough. The uneven surface of the moraine is sparsely dotted with boulders, often five or ten feet and occasionally fifteen feet in diameter. The morainic hills gradually rise 350 feet over the lake to an elevation of something more than 2,400 feet: and there fall toward the beginning of the great Pend Oreille-Spokane outwash plain, to which the next section is devoted.

The Pend Oreille-Spokane Outwash Plain.—Lake Pend Oreille lies near the western border of the Rocky Mountain system: to the east of it, the mountainous highlands are relatively continuous for many miles; to the west they are divided into a number of small isolated masses, separated by irregular depressions, as in Fig. 1. The mountain slopes bordering these open depressions, as well as some of the valleys that penetrate farther eastward into the mountainous highland, are discontinuously terraced by lava-flow benches, from which it must be inferd that, after the mountains which enclose the depressions had assumed much of their present form by long continued erosion, they were encroacht upon by and partly submerged beneath the successiv flows of the rising floods of lava which built up the vast lava plains of the Columbia basin; and that the lava plains

were afterwards greatly dissected and the intermont depressions were again widely opend along the margin of the mountainous highlands. It is one of these re-excavated depressions, limited on the southeast by the Coeur d'Alene mountain mass, by the Mica-peak mass on the south, and on the northwest by the outlying Mount Carlton mass, that is heavily filld to a width of from four to ten miles as far as Spokane and beyond, with the great gravel outwash plain of the Pend Oreille glacier. Thus the visible depth of the depression between the mountains is much decreast. The altitude of the plain at its beginning near the end of Lake Pend Oreille is about 2,400 feet; at Spokane, 45 miles to the southwest, it is about 2,000 feet. Its depth is unknown by direct measurement, but in a later paragraph on Lake Coeur d'Alene, evidence will be given to show that a depth of over 400 feet is probable.

Many boulders among the gravels are from two to four feet in diameter, and some are still larger; hence the glacial river by which such blocks were washt twenty or thirty miles from the end of the ice must have been large and vigorous: it may well have been so if it discharged as ice water all or nearly all the huge tongue of ice that crept southward through the great trough of Lake Pend Oreille.

Steepend Mountain Flanks Bordering the Outwash Plain.—Further evidence of the vigor of the ice-water river is found in the steepening or refreshment of the slope of a lava bench that flanks the mountains on the east, some twelve or more miles southwest of the end of the lake. Instead of presenting a graded slope, such as commonly borders the residual benches of the maturely dissected lava sheets elsewhere, the bench here breaks off to the gravel plain in a steep scarp, as if it had been actively scourd and undercut by the current of a strong stream along its base. The scarp of a lava mesa west of Spokane is similarly refresht where it borders the gravel plain. Other instances of similarly undercut slopes will be mentiond below.

The brief views that I had of two side valleys, both joining the main trough at Spokane—one, that of Little Spokane river, to the north, the other, that of Latah (formerly Hangman's) creek, to the south—showd the outwash there to be composed chiefly of finer gravels and sands, as might be expected from their position to one side or the other of the main outwash. Bricks are made from clays that occur in a side valley eroded in the lava plateau a few miles southwest of Spokane: I had no opportunity of examining the clays, but venture to suppose that they are the fine sediments which slowly accumulated in the side valley while it was ponded by the more rapidly aggrading gravels of the main outwash.

The Broad Channel in the Outwash Plain.— The original surface of the main outwash plain is now interrupted by a broadly eroded channel having depths of 30, 50 or 100 feet, and the channel thus appears to be borderd by terraces, wider on the southeast side toward the main body of the Coeur d'Alene mountains and on the south toward the advancing mass of Mica peak; narrower on the northwest along the base of the isolated Mt. Carlton mass. As no stream now follows the greater length of the broadly eroded channel between the terraces, the excavation may be regarded as the work of a clarified and degrading ice-water river, issuing on the gravel plain from the southern end of Lake Pend Oreille at a level somewhat below 2,500 feet, when the ice had melted back a few miles but not far enough to open a lower passage farther north where the lake finds it present outlet; for such a stream would have left its sediments in the lake, and would therefore be able to cut a channel thru the plain which its unfilterd predecessor had built up.

Hoodoo Lake.—While the channel of the outwash plain was going on, the lateral streams, such as Little Spokane river and Latah creek, terraced the finer deposits of their lateral valleys. Some further details in this connection are given in a later section in which the lakes enclosed by the gravel outwash are described. Mention may be made in this connection of a long and narrow depression, half a mile or a mile in width at an altitude of between 2,100 and 2,200 feet, running west from Squaw bay, the northern one of the two southwestern bays of Lake Pend Oreille, for about ten miles, and then northward for ten miles more to Clark fork. The northward turn of this depression is occupied for some seven miles by the narrow and marshy Hoodoo lake. This may mark a temporary lake outlet of late glacial date. I saw only the eastern part of the depression; the description of the rest is taken from the maps of the Rathdrum and Sandpoint quadrangles.

Spokane River.—Some ten or fifteen miles east of Spokane the river of the same name, coming from Lake Coeur d'Alene, enters the broad channel in the gravel plain, and continues on a smaller scale the work of sweeping away the gravels that had been previously begun by the extinct ice-water river. The depth of incision by Spokane river east of the city is however limited by its superposition on a lava bed within the city limits, of which more is said below. When one crosses the outwash plain from north to south, the channel is easily recognized; but when one looks eastward along the plain, as one may from the rim of the lava plateau west of Spokane, the channel can hardly be detected, except in the immediate foreground: the out-

wash then seems to be a smooth plain. When this district was first settled the plain was regarded as a barren waste; it is now partly irrigated and occupied by thriving farms and orchards.

The Lone Mountain Gravel Mesa.—Lone mountain (L. Fig. 1), two miles in diameter and 3,400 feet in altitude, rises nearly 1,000 feet over the general surface of the gravel outwash, twelve miles southwest of the long arm of Lake Pend Oreille and three miles east of the Mt. Carlton mass. When viewd from the plain on the southeast (2,300′) the mountain is seen to be flankt on both sides by benches (2,400′) which were mistaken in the distance for lava mesas, as they repeated the appearance of the well defined mountain-flank lava bench which borders the outwash plain hereabouts along its eastern border. A closer view showd the benches to be a mass of moraine and gravel, evidently reduced by lateral erosion from a former greater extent. To the northeast of Lone mountain, the washt scarp of the mesa is dotted with boulders, some of which are ten or fifteen feet in diameter. The surface of the mesa was found to be rolling, with low hills and shallow hollows. The arm of the mesa to the southwest of the mountain was not crost; but so far as could be judged it was there more like an outwash than a moraine deposit. The north slope of Lone mountain was strongly clift for 100 feet or more over its visible base, as if by ice scour or river undercutting.

The following suppositions may be made in connection with this high-level moraine and gravel mass. It has already been stated that the Kootenai-Flathead glacier has left two well markt moraines, separated by a distance of fifteen miles or more; the Bitterroot valley moraines, south of Missoula, also show a greater earlier, and a smaller later advance, as I saw during a brief visit in 1909. Hence the Kootenai- Flathead glacier probably had a similar two-fold advance. When this glacier first reacht the Pend Oreille district, the present lake trough was occupied by a valley of which the floor, as above shown, lay not much below the present lake surface. During the occupation of the valley by ice, it was deepend about 1,000 feet and its side slopes were scourd off into steep cliffs. Hence on the first coming of the glacier, the pathway through what is now the lake could not lead nearly so much of the ice stream as on the second coming; more of the first ice stream must therefore have turnd southwest, through the depressions between the isolated mountains. One of these earlier glacial arms may have past south along Hoodoo valley and built up the higher moraine and gravel mass in a large area around Lone mountain and beyond it; but when the Pend Oreille trough was deepend, a larger and larger part of the second glacial advance should have flowed through it, and the southwestern glacial arm must then

have been less extensiv. The increast ice-water outflow from the south end of the lake must finally have cut away all but the present Lone mountain remnants of the earlier and higher deposits.

Lake Coeur d'Alene.—The valleys that descend from the mountains to the outwash plain of the Pend Oreille glacier are bard, as several observers have noted, by the heavy deposits of outwasht gravel that stretch across their lower courses, and many of the valleys therefore hold lakes. The finest and largest example of the kind is Coeur d'Alene lake, which extends into the Coeur d'Alene mountains twenty miles south of the closed outlet at the mountain border, where a town of the same name lies, 28 miles east of Spokane. The gravel plain there has a height of 2,200 feet; Spokane river, the outlet of the lake, flows westward close along the mountain border on the south, as if pusht there by the aggradation of the outwash plain from the north. Seven miles west of the lake the river is superposed on the resistant rocks of a formerly buried mountain spur; down stream from the spur, the river course is more deeply incised in the gravels and its valley is well opend, as is usual in such cases. The river, divided into several streams, has cut as many small gorges across the rocky spur, and each gorge has falls at its head. The manufacturing village of Post Falls is there located. The graded course of the river up stream from the falls determins the present altitude of Lake Coeur d'Alene at 2,124 feet. The depth of the lake is said to be 400 feet not far from the outlet, and it is upon this record that a somewhat greater depth than 400 feet is inferd for the gravels in the middle of the outwash plain, as above noted.

Several branching valleys, now drownd in the arms of the lake, are enclosed by subdued mountains which rise to altitudes of 4,000 or 4,500 feet. Their slopes are often rimd with narrow lava benches at altitudes of from 2,300 to 2,500 feet. Hence, as already explaind, the lake arms represent valleys of two erosion periods, one before and one after the lava out-pouring; and it may now be added that the valleys have sufferd two drownings, long ago to a high level by the rising arms of the vast lava sea, now to a lower level by the ponded waters of the present lake. The two chief arms of the lake branch eastward from its southern point, and are enterd by rivers Coeur d'Alene and St. Joe, which come from the mountains of the Coeur d'Alene mining district farther east. The lake arms were originally some twenty miles long, but are now partly filld with delta flats.

The delta thru which the navigable waters of St. Joe River flow into the lake projects in two long, slender points, standing four or five feet above the river when I saw them, and sloping away on either side to marsh or lake level in a distance of two or three hundred feet, evi-

dently the results of turbid flood overflows. The points are tree lined near the river and grass-coverd farther back. A few miles above the delta points, the flats occupy the whole breadth of the drownd branch valleys; and there a number of secondary arms of the lake still remain as unfilld ponds; thus illustrating in a small way the origin of Lake Coeur d'Alene itself. The shore line of the present lake level is hardly modified by wave work; no shore lines were seen at higher levels; occasional low lava benches simulate abandond shore lines, but they are probably altogether of subaerial origin.

Other Lakes Enclosed by the Gravel Outwash.—Six other mountain valleys in this district are enclosed by the outwasht gravel plain so as to hold small lakes, and a few more hold marshes that were formerly small lakes. A small valley a mile to the east of the north end of Lake Coeur d'Alene is barred by the part of the outwash on which the town of Coeur d'Alene stands, and holds Fernan lake, about three miles in length, east to west, at an altitude of 2,129 feet. Six miles farther north, where the outwash plain stretches along the western flank of the mountains, which here reach heights of 5,000 feet, lies Hayden lake, the largest member of the smaller group, at an altitude of 2,242 feet. Its eastern shore has a number of drownd valley bays, somewhat shortend by deltas; most of its western shore is borderd by lava benches, a breach to the south of which indicates the probable former valley by which the trunk stream of half a dozen mountain branches made its escape to the plains.

The breach is now closed by the gravel plain at a height of nearly 2,300 feet; the resulting lake is about six miles in length from northeast to southwest. A shallow depression across the outwash plain to the southwest looks like the path of a former lake outlet; the lake water now escapes by percolation. When first known the lake was about four feet lower than now; a farmer who wisht to lower the lake a little more, so as to drain a swampy meadow at the former outlet, fired a blast where some of the water ran into the base of the lava slope on the south; but the blast obstructed the passage of escape and the lake rose four feet, killing the trees round its border and submerging several small baybars, apparently wave-built, but locally known as "beaver dams." Water is pumpt from the lake into irrigation canals for the gravel plain to the west.

If instead of going north from Lake Coeur d'Alene, we turn west along the northern border of the Mica Peak (5,250′) mountain mass, two obstructed valleys are found. The first is 15 miles east of Spokane and holds Liberty lake (2,052′), two miles long with a marshy delta at its head: it is reacht by electric railway from Spokane and serves as a pleasure resort. Two miles to the west, the valley of Saltese

creek has a marshy floor. Like Lake Coeur d'Alene, both these valleys have their outlets at the western side of the enclosing gravel deposits, as if pusht there by the aggrading gravels.

The mountain mass which culminates in Mt. Carlton (5,805′), 22 miles northeast of Spokane, and limits the outwash plain on the northwest, measures over twenty miles north and south, by about fifteen east and west. Four of its southeastern valleys contain lakes. The largest, known as Spirit lake (2,422′), Fig. 6, occupies four miles of the lower part of a valley that descends directly eastward from Mt. Carlton; the inflowing stream, Brickel creek, has formd a delta over a mile in length; the outlet, Spirit creek, turns north and then west between the Mt. Carlton mass and a smaller mass, with an unnamed summit (5,091′) on the north. The Spokane Chautauqua holds its meetings on the north side of the lake.

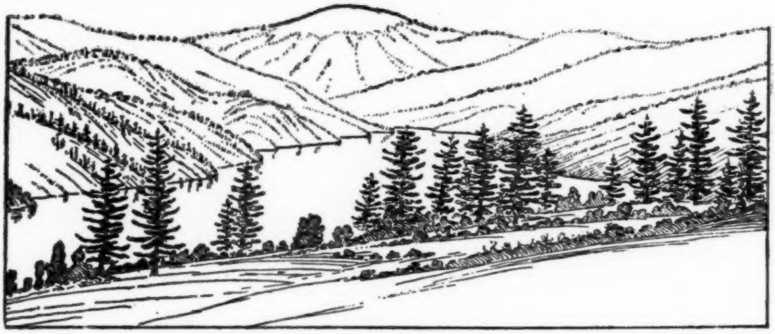

FIG. 6. Spirit Lake below Mount Carlton, looking East.

Three miles farther south, a similar valley holds Fisk lake (2,314′), nearly four miles in length; the outlet turns to the south along the mountain base, as if pusht there by the aggrading gravels. After passing two other small valleys, which seem to be enclosed as seen from the outside, and in the second of which the Rathdrum map shows a mile of marsh, one finds two other larger valleys in the southern flank of the mountain mass, holding Sucker (locally known as Hauser, 2,191′) and Newman (2,130′) lakes, one and two and a half miles long respectivly. The gravel benches stretching from spur to spur, back of which these lakes lie enclosed, look like artificial embankments when seen from a distance. They are narrow, because the broad channel excavated in the outwash gravel plain here has its border close to the mountain base. Indeed the northward widening of the broad channel seems to have been limited hereabouts by the rocky spurs, which end in steepend ledges or cliffs of small

height, worn back even with terraces cut in the gravels at one or more levels but often interrupted by outstanding, incompletely removed stacks.

All of these features, like the refresht lava scarps already mentiond, testify to the vigor of the ice-water river by which the broad channel was excavated in the gravel plain; but in this case the cut-back spur ends are, like the gravel-plain channel, the work of the clarified ice-water river in its later or degrading phase. The refresht lava scarps above mentiond on the eastern border of the highest outwasht gravels mark the work of the river in its earlier, aggrading phase. Between the cut-back spur ends above mentiond, the upper terrace scarp of the gravel bench is concave toward the broad channel in the outwash plain. This shows the work of the terracing river, sweeping laterally against the gravels as far as permitted by the resistant spurs, which were more slowly cut back. The slope of the gravel bench or embankment into the valley occupied by Newman lake has the form of delta-lobes, presumably built by small distributaries which flowd gently from the main aggrading ice-water river into this valley embayment. No traces of ice-action were seen in this district. Hence I doubt the correctness of the diagram facing page 144 of the Northern Pacific Route Guide Book (U. S. Geol. Surv., Bull. 611), in which a southwestern lobe of the ice sheet that bard Lake Missoula is represented as reaching Spokane. The morainic part of the Lone mountain mesa, described above, is the most advanced glacial deposit that I saw, and this is thirty miles northeast of Spokane.

If there ever were a lake enclosed in the valley of Latah creek, south of Spokane, it has been draind by the terracing stream, which has successfully re-opend its former valley. The valley of Little Spokane river also has no lake, presumably because of the deep entrenchment of the river in the outwash deposits. In this case it is probable that the broad gravel plain north of Spokane buries for some eight miles the former path of this tributary, for the Little Spokane now turns west just north of the gravel plain and makes its way by a much narrower passage between a lava mesa known as Five-mile prairie and a low mountain outpost north of it, to the main river.

The District Around Spokane.—The highest lava beds in the Spokane district stand at altitudes of about 2,500 feet. Their original continuity is now, as has been already stated, broadly interrupted hereabouts by the erosion of the open valleys of Spokane river and its branches. The uppermost beds are now seen only as comparativly narrow benches rimming the mountain flanks, or as partly or wholly isolated mesas, of which Pleasant prairie and Five-mile prairie, a few miles northeast and northwest of Spokane, are fine examples. These

two mesas have evidently taken their family name because of having a treeless upper surface: their escarpments, descending to lower levels in graded slopes which seldom exhibit bold outcrops, are usually wooded. The mesa surfaces or "prairies" have a deep and fertile soil, and are occupied by prosperous farms on which irrigation is unnecessary.

Farther west, where practically the whole country is occupied by lavas, the mountain outposts of the Spokane district are prolongd by lava-sheet spurs, as parts of a dissected plateau, but these spurs are at a lower level than the residual lava rims on the mountain slopes. The eastern border of the plateau two miles west of Spokane, along which a parkway road is in construction, offers a fine view of the several elements of the landscape here described. The deep valley of Spokane river, below the falls by which the location of the city is determind, is in the foreground, the river being 400 feet below the plateau rim; the subdued mountain group culminating in Mount Mica (5,250′) rises twenty miles to the east; another mountain group, culminating in Mt. Carlton (5,805′) also known as "Spokane mountain" and "Old Baldy," rises 22 miles to the northeast, besides some other smaller elevations of the same kind. Lava benches are seen discontinuously rimming the mountains, and lava mesas stand forth between them; finally in the distant background is the main body of the Coeur d'Alene mountains, south of Lake Pend Oreille, 35 or 40 miles away, beyond which a succession of mountains forms the great barrier between the East and the Far West.

Location of the City of Spokane.—Spokane is situated where the river of the same name, superposed on a lava bed while channeling the great gravel plain, cascades into what seems to be a re-excavated part of its preglacial valley. The location of the city close to the overlapping contact of the broad Columbia lava plateau with the western flank of the Rocky Mountains, gives it the advantageous variety of relations that is usually associated with natural boundary lines; and its position not far from the deep transverse valleys of Clark fork and Kootenai river through the mountains makes it a node of many converging railway lines, five of which have transcontinental rank. The important Coeur d'Alene mining district lies in the highlands to the east. The neighboring physiographic features are of varied interest: the superposed course of the river, as above noted, is one of them. Gravel terraces are well seen to the north of the city, the suburb of Lidgerwood standing on the higher one: also farther down the river valley, where they are associated with low-lying lava benches. Higher lava benches rise in the southern part of the city: there the recent development of a residential quarter has been skilfully pland

to accord with the form of the surface; the rigid scheme of squared streets which so often permanently disfigures a pleasing landscape for the short-lived convenience of dealers in rectangular lots, is here replaced by a system of gracefully curvd avenues, so sympathetic with the local relief as to enhance its beauty.

Steptoe Butte.—A brief digression may be here allowed to describe a fine example of an outlying mountain isolated in the lava plateau and known as Steptoe Butte, first reported by Russell.[17] It is fifty miles south of Spokane and ten miles west of the general mountain border, in that part of the plateau known as the Palouse country. There the surface is elaborately carvd into a relief of one or two hundred feet by the countless insequent branches of a mature or late-mature valley system, and deeply coverd with an impalpably fine soil, so that only the trunk valleys, sunk into the underlying lava beds with frequent outcropping ledges on their lower slopes, have running streams. The intricate contour lines of the Oakesdale quadrangle, United States Geological Survey, testify to the detail of dissection, but do not represent all of its minuteness. Steptoe butte is a treeless knob of quartzitic beds, which dip to the southwest; its summit rises 1,000 feet over the general surface of the plateau to an altitude of 3,613 feet. The hotel that stood on its summit at the time of Russell's visit has been burnd, and the road up the longer western slope is badly washt. The delicately sculptured surface of the plateau around the base and to the north, west and south is a vast expanse of rich farm lands, originally treeless tho small patches of trees are now growing near most of the farm houses; it was tinted at the time of my visit in three colors; the green of alfalfa, the yellow of harvested fields, and the neutral shade of plowd fallow land. To the west the horizon is unbroken; sixty miles to the south rises the broad low dome of the Blue mountains, a dissected uplift of the Columbia lavas, according to Russell; to the north a few low mountain outposts are seen; to the east beyond an intervening plateau belt of some ten miles, rise the subdued border ranges of the Rocky Mountain system, the transition from one province to the other being irregular but well markt.

Russell explaind the deep soil of the Palouse country as due to local weathering of the underlying lava. An alternative explanation ascribes it in large measure to dust brought by the prevailing winds from the drier part of the plateau farther west and caught here by the richer herbage, the growth of which is favord by the increasing

[17] I. C. Russell, Reconnaissance in Southeastern Washington, U. S. Geol. Surv., Water Supply . . . Papers, No. 4, 1897.

rainfall provoked by the approach of the winds to the mountains. Under both explanations, dissection must have gone on, chiefly by wash and creep, during accumulation. It is curious to note that the plateau farther north toward Spokane, where the climate is moist enough to support an open growth of pines, often has a thin, stony soil.

THE VALLEY OF UPPER CLARK FORK. *The valley for sixty miles above Lake Pend Oreille.* We may now turn to the valley of Upper Clark fork, the study of which was the prime object of my journey. Other districts have been described first, in order to make sure of the main element of the problem, namely, the upstream invasion of at least a part of Upper Clark fork valley by a distributary of the great Kootenai-Pend Oreille glacier. That there was some such invasion no doubt can remain, but its extent is undetermind. My censor judicously urges that, as the other distributaries of the great glacier were not of extraordinary length, this southeastern one cannot have ascended Upper Clark fork valley very far. He therefore ascribes whatever ice erosion was done at points 50 or 100 miles distant from Lake Pend Oreille to an invading glacier or glaciers of more local origin, perhaps altogether detacht from and independent of the Pend Oreille distributary. The problems thus raised must be settled by an examination of the peculiar features of the valley, to which we now turn. The description will proceed up-stream, from northwest to southeast. It may be noted that the area over which marks of ice erosion are found is significantly greater than the glaciated area represented for this valley in the Northern Pacific Guide Book (diagram facing p. 144).

For the first 60 miles southeast of Lake Pend Oreille, the valley of Upper Clark fork has a width of from two to five miles; its floor is heavily covered with drift deposits which are frequently trenchd and terraced by the river; ledges occasionally rise thru the drift; the river is locally superposed on the rocks of the valley floor at one point, where it has cut a narrow cleft, known as Cabinet gorge. The valley sides in this long stretch were not well seen in my trips by train, but where they were visible, features which I noted as "scourd ledges and clift slopes" occurd. Other observers have, however, according to comments by the censor of this paper, found the side slopes in this stretch of the valley to be cloakd with residual soil; hence they exclude recent glacial erosion hereabouts.

The Thompson Falls Basin and Moraine.—At a point 60 miles southeast of Lake Pend Oreille, the valley of Upper Clark fork widens in a flat-floord basin measuring four of five miles across. The northwestern corner of the basin is occupied by a heavy morainic

mass a mile or two in width, on which I had a two-hour walk. Its rolling surface, sparsely dotted with boulders, rises from 200 to 350 feet over the basin floor next up stream. Glacial action at this point is unquestionable, altho the source of the glacier has not been determind surely. Its possible origin is suggested below. The river is turnd by the moraine to the southwestern side of the basin, where it is locally superposed on a strong valley-side spur, from which it cascades into a trench deeply incised in the drift and thus enters the lower sixty-mile stretch of its valley. The village of Thompson Falls lies near by. The Northern Pacific railway has a freight-line détour thru the drift trench for a number of miles, while its passenger trains follow a line on the broad drift bench. The Chicago, Milwaukee and St. Paul railway has constructed an electric power station at the falls, by which the trains of its mountain division are driven for several hundred miles.

The side slopes of the Thompson Falls basin have the moderate declivity and dissected form due to mature normal erosion. The aggraded basin floor (2,400′) is occupied by farms, and is borderd on the north by a number of low but well formd river terraces, some of which appear to be defended by boulder-set cusps of the moraine. The Northern Pacific railroad makes a gentle turn around one of the cusps a mile east of the station.

The Woodin-Weeksville Narrows.—The valley narrows about four miles east of Thompson Falls, and thereupon the walls become strongly clift and scourd, and so they continue for some 13 miles farther past Woodin, Eddy (2,437′) and Weeksville (2,453′) stations. On the northern side of the narrows near Eddy, the slopes of the normally rounded highland domes are cut back in bold cliffs, from which long talus slopes descend, continuously or interrupted by intermediate cliffs, to heavily scourd ledges near the level of the aggraded valley floor. On the southern side of the narrows, the cliffs truncate spurs and lateral valleys in the most impressive manner; large scourd and pluckt ledges interrupt the flat valley floor near the cliff base. These narrows would well repay more attentive study.

The Plains Basin.—The narrows are followed next up stream by an open basin, a few miles in diameter, with an aggraded floor on which a village has taken the appropriate name of Plains (2,482′): some low hills near by were interpreted as moraines; a higher bare hill, free from ledges and possibly a moraine like its lower neighbors, is delicately markt by seven or eight faint shore lines of Lake Missoula; these are the westernmost examples of their kind that I recognized. I had no means of determining whether the basin-like expansions of

the valley at and above Thompson Falls and at Plains are normally eroded excavations in areas of less resistant rocks, or small fault troughs, less uplifted than the adjoining highland masses; but the latter origin is confidently asserted for them in the Guidebook for the Northern Pacific Route (143). It may be at once noted that the Plains basin appears to offer an available path by which a glacier from the Cabinet mountains on the north may have reacht the valley of Upper Clark fork, and then flowd down valley as far as the Thompson Falls moraine and crept up valley to the farthest observd signs of valley-side scouring. This matter is further considerd in a later section.

FIG. 7. Truncated spur in Clark Fork valley near Paradise, looking northwest.

The Paradise District.—The valley resumes its small width of a mile, more or less, with a flat, aggraded floor above the Plains basin, and here I spent three days with the small village of Paradise (2,499′) as headquarters. The sharp backhanded turn, by which Clark fork makes its way eastward from another southeast-northwest valley to receive Flathead river from the upper part of the valley thus far described, opens a mile above Paradise. Scourd and clift slopes at Paradise and in the Flathead section of the valley were seen for 22 miles above the Plains basin; they disappear near McDonald station (2,520′ ?). Similar scourd slopes were traced for several miles into the backhanded turn of Clark fork, as will be more fully stated below. The rocks hereabouts are quartzitic sandstones, similar to those seen in various other districts. Near Paradise, their

dip is steep to the southwest, but they are so uniformly resistant that the smaller valleys are of insequent habit, and all the hills and spurs are indifferent to rock structure. The highlands in which the valleys are incised were seen only from the valleys, but the distant skyline as seen in many views was so gently undulating as to warrant the description of the district as an uplifted, submaturely dissected peneplain. But it seems hardly warranted to describe the peneplain as having been "as flat as the prairies of North Dakota" (Guidebook, Northern Pacific Route, 153), unless prairies of strongly rolling form, not remarkable for their flatness, are intended.

The pronounced truncation of the valley-side spurs is strikingly exhibited in the view down stream from near Paradise, as represented in Fig. 7: the upper slopes are of moderate declivity, smooth and soil coverd, with every appearance of having resulted from long continued normal erosion; the lower slopes are steep and rugged, exhibiting many bare ledges, with every sign of vigorous scouring and plucking by glacial action, so recently extinct that the growing talus has not yet equalized the uneven descent. The lowest visible ledges pitch under the stratified drift of the valley floor, the total depth of which must be much greater than the 30 feet of gravel penetrated by a well near the station. The widend valley floor in the middle distance of Fig. 7 is part of the Plains basin: the beginning of the Weeksville-Eddy narrows is shown in the background at the left side of the figure. As was noted in the introductory pages, the details of this sketch and of several others in the same district must not be taken as exact; the ledges were not measured, the trees were not counted, nor were the valley-floor fields surveyed; nevertheless, trees and ledges and fields may serve, as here drawn, to suggest the character of the actual landscape.

Valley-Side Cliffs are not Fault Scarps.—It may perhaps be suggested that the valley-side cliffs, here ascribed to erosion by a valley glacier, are in reality due to faulting; but if so, the faulting must be of very recent date, much more recent than the basin faulting which is associated with the warping uplift of the mountainous highlands. For since the faulting of that epoch, the highlands have been submaturely dissected by small streams, whose valley sides are well opend and coverd with a graded sheet of creeping soil; while the valley-side cliffs here examind are of a much more modern date, for they undercut the graded slope of the highlands above them, and they still exhibit an abundance of bare rock, not yet reduced to moderate slopes by weathering. Again, if the cliffs are due to faulting, the faults must have a singularly close relation to the sides of a valley

of earlier origin; and this is inherently improbable. Moreover the cliffing and scouring of the valley sides weakens and disappears upstream, as described below, in a manner that is highly characteristic of the lessening work of a dwindling glacier, but not at all characteristic of faulting. Finally, the valley-side cliffs correspond closely with the spur-end cliffs already described along the margins of the Swan and Mission ranges in the Kootenai- Flathead depression. The explanation of the cliffs by faulting appears to me to be excluded.

It may perhaps be suggested that the valley-side cliffs are the product of revived river erosion, whereby a young and steep-sided valley was

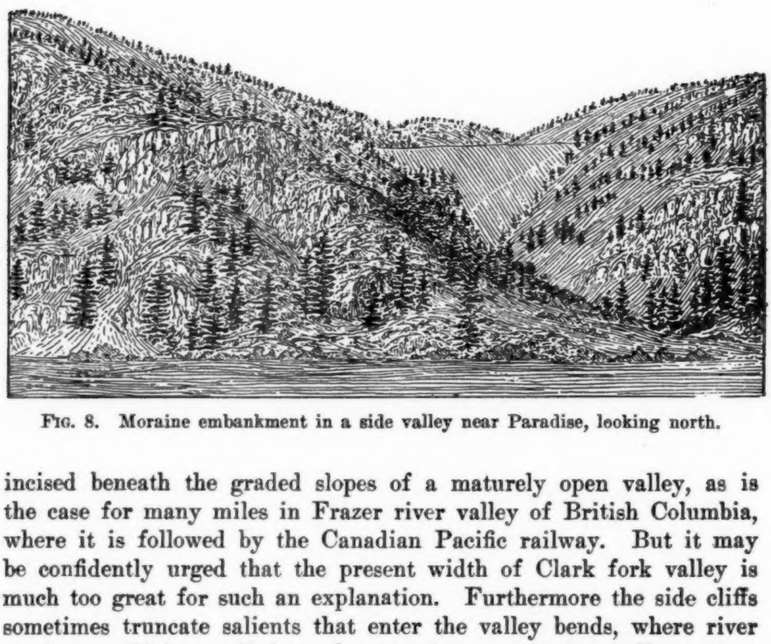

FIG. 8. Moraine embankment in a side valley near Paradise, looking north.

incised beneath the graded slopes of a maturely open valley, as is the case for many miles in Frazer river valley of British Columbia, where it is followed by the Canadian Pacific railway. But it may be confidently urged that the present width of Clark fork valley is much too great for such an explanation. Furthermore the side cliffs sometimes truncate salients that enter the valley bends, where river erosion would be applied on the opposite or reentrant valley curve; a good example of this kind above Paradise is described in a later paragraph. Again, as shown in Figs. 10 and 11, the cliffs are often benched in a manner that seems beyond explanation by normal erosion on the side of a river-cut valley.

On the other hand, it may be objected that, if the cliffs are attributed to glacial erosion, striated rock surfaces, perched boulders, and morainic deposits should be associated with them; and none of these characteristic consequences of strong glacial erosion are conspicuous hereabouts. Indeed, perhaps because my search was hurried, I nowhere saw any glacial striations in Clark fork valley. The exposed ledges,

altho often well rounded, are so roughend by weathering as to have lost any striations that they may have once possesst. Yet I cannot doubt that if the drift and soil cover were removed, glacial striations would be found.

Moraines in Lateral Valleys.—Three side valleys not far below Paradise present independent evidence of glacial action in the form of transverse morainic embankments of small size, 400 or 500 feet above the main valley floor; one of them is sketched in Fig. 8, but as my point of view was on the valley floor, not far from the scourd base of the valley side, the figure does not give an adequate impression

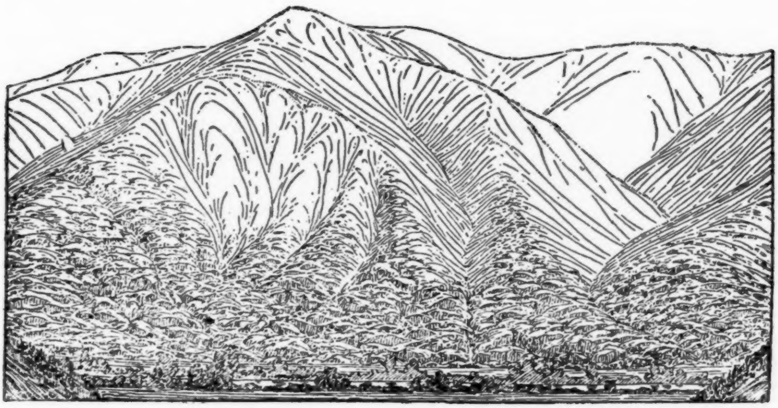

Fig. 9. Scourd side of Clark Fork valley near Paradise, looking southwest.

of the height of the moraine. I walkt up to its crest and found it to lie somewhat back of the spur-end cliffs, with a steep slope toward the main valley and a gentle slope into the side valley, where a swampy hollow lay well below the embankment a quarter mile upstream. The slopes of the embankment were grasst over; no large boulders were seen; a few cobbles of crystalline rocks were found. I must dissent from the interpretation of these embankments as "deltas or terraces," marking "the mouths of small streams which at one time flowed into a lake whose surface was at the level of the terrace," as announced in the Guide book of the Northern Pacific Route (142); the back slope into the side-valley and the occurrence of crystalline cobbles suffices to exclude this explanation.

The view from the moraine across the main valley, too much schematized in Fig. 9, showd the southwestern valley side to be only moderately scourd, yet well enough to give a cascading quality to the lower course of some small streams where they descend from mature,

normal side ravines over ragged basal ledges. Stronger cliffs are seen farther up the main valley, on its northeastern side, as in Figs. 10 and 11. Here the interruption of the steepend descent by scourd ledges at intermediate heights was strongly developed. As before noted, such ledges would not characterize a valley deepend by river erosion alone; but they are expectable in a river valley that has been imperfectly scourd by an invading glacier.

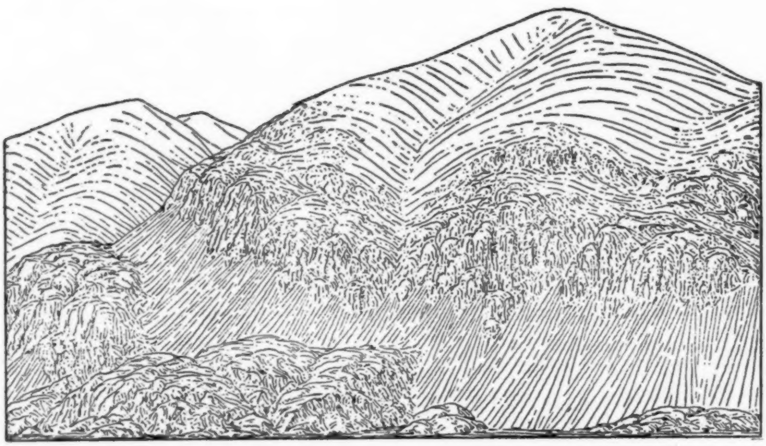

FIG. 10. Scourd and bencht side of Clark Fork valley near Paradise, looking north.

A Truncated Salient above Paradise.—The most remarkable example of a completely truncated salient in the Paradise district, Fig. 12, is seen on the north side of the valley, about two miles upstream from the village, and almost opposit the entrance of Clark fork from its backhanded turn. The salient advances toward a concave reentrant in the other valley wall, and hence is as above noted, precisely in the position where the river could not truncate it. But a glacier, occupying the whole breadth of the valley and striving to reduce its bends, would exert a great scouring pressure on such a salient and would eventually cut it off whether the ice moved up stream or down stream. The truncation of this salient is similar to the demolition of the spurs in the meandering valley of the Dordogne in central France, where in the winter of 1898-99 I first realized how powerfully an invading glacier could remodel a previously eroded river valley. The spurs that normally project into the turns of the Dordogne valley are more or less completely destroyd in the upper part of the valley where it bears the marks of invasion by a local glacier that descended from the

volcanic mountain of the Cantal not far away; farther down stream the meandering valley retains its normal form.

The truncation of the Clark fork salient above Paradise, just considerd, as well as the truncation of other salients and the general steepening of the valley-side walls, should therefore be recognized as consistent with the observd effects of eroding glaciers elsewhere. Indeed all the evidence points to glacial erosion as the cause of these truncating valley-side cliffs. The clift face of the salient here in question is merely one of many spur-end cliffs in Upper Clark fork valley; it is more pronounced in its height of 400 or 500 feet than most of its neighbors, but it is exceeded in height and in length by the cliffs of the Woodin-Weeksville narrows.

Less emphatic marks of glacial scouring are seen on the upper slope of the salient just described, as well as on other salients and spurs, for one or two hundred feet above the top of the main cliffs; but apart from these subordinate, high-level roughnesses the mountain mass has a well subdued form with a smoothly graded, waste-coverd surface. Unfortunately the traveller by train is not allowd a good view of this impressive feature, as the Northern Pacific railway follows the base of the long talus slope, which for part of its spread is swept by the river; and altho the view from the train up the talus slope to the cliffs that tower above is impressive by itself, it lacks the suggestiv lesson given by the contrast between the abrupt and bare face of the cliffs and the rounded, waste-coverd slopes above them, as seen from the middle of the valley floor.

The Backhanded Turn of Clark Fork Valley.—The advance of a short branch of the invading glacier into the backhanded turn of the Clark fork valley near Paradise is another surprising feature of this district. It should be rememberd that Uppermost Clark fork, after pursuing an almost northwestward valley thru the mountains for about 100 miles—a stretch on which Deer Lodge, Missoula and St. Regis lie at the beginning, near-middle, and end—swings around nearly to the east and thus runs for about 12 miles, in the backhanded connecting valley, to the neighboring northwestward valley where it receives Flathead river from the eastsouthwest. There it resumes a northwestward course and so runs for nearly 90 miles to Lake Pend Oreille. Glacial scouring of valley-side spurs is traceable not only for some ten miles up the valley of Flathead river above its junction with Clark fork at the Paradise turn, but also for four or five miles into the backhanded turn of the Clark fork valley toward St. Regis. A railroad trip by a freight train from Paradise to St. Regis and farther up stream toward Missoula showd that the spurs of the valley side which faces northwest at the entrance to the turn, are severely

truncated in rugged forms for the first mile or more. Here the rocks are seen to dip steeply to the southwest. The many joints by which they are transected exercise much control at present on the details of the cliff-face forms, but the peculiar disposition of their oblique lines makes it impossible here, as on Kootenai lake, to believe that similar joints have exerted any controlling influence on the course of the branching valleys in the mountain sides above or beyond the area of glaciation. Farther up the turn (westward), the normal form of valley-side spurs is better preservd, altho they are still abundantly scourd and pluckt for three or four hundred feet above the river. Then for about two-thirds of the length of the turn, all

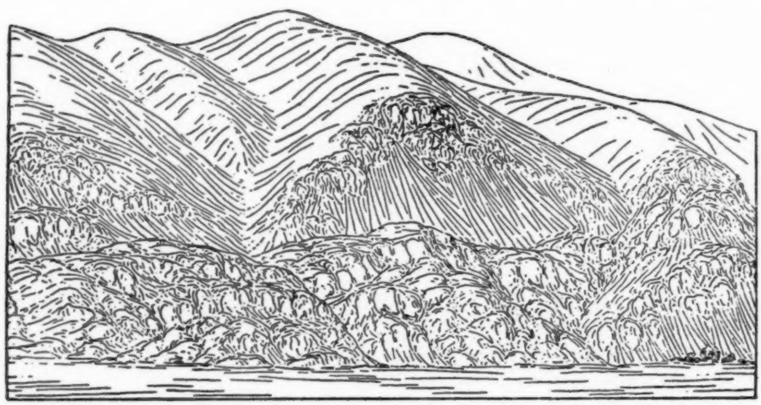

FIG. 11. Scourd and bencht side of Clark Fork valley near Paradise, looking northeast.

signs of glacial scouring vanish; the waste-coverd mountain salients are normally prolongd into the bends of the valley, which assumes so meandering a habit that the railway repeatedly bridges the river and tunnels the spurs in order to shorten its track. But whether the tunnels are in rock or in gravel I could not determine, as just here a series of unusually heavy drift terraces begins.

Upstream or southeast from St. Regis (2,647′) the valley of Uppermost Clark fork is more open; its side slopes are normally carvd, and occasionally show faint shoreline terraces where tree growth is wanting; stream terraces occupy the narrow valley bottom for fifty or one hundred feet over the river. At a number of points on this side-line excursion, views of the comparatively even skyline of the highlands were obtaind, which taken in connection with the steep dip of the rocks seem here as elsewhere to compel the interpretation of

the highland as an uplifted old-mountain region, probably deserving to be calld a peneplain, in which the valleys are the work of a later cycle of erosion.

Scourd Cliffs in Flathead Valley.—If we now return again to the main path of the Clark fork glacier and follow it up Flathead valley, which is locally narrowd for several miles, an abundance of glacially truncated, scourd, and torn spurs may be seen below the normal forms of the higher slopes for six or eight miles above Paradise; gulches are sometimes opend in the cliff faces transversely across the spurs, as if guided by master joints or faults. Four small

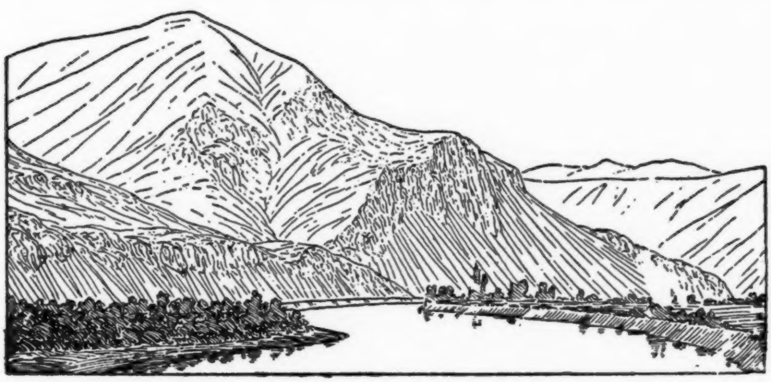

FIG. 12. A truncated salient in Clark Fork valley above Paradise, looking east.

embankments, believd to be moraines, were seen barring side valleys several hundred feet above the stream; one of them is notchd by its stream. The Guidebook of the Northern Pacific Route gives an empirical account of this part of the valley:—" The canyon is deep and narrow, and its walls are very precipitous . . . several diorite sills are conspicuously exposed. . . . The valley has high, rocky walls that rise 1,500 to 2,500 feet above the valley floor. The rocks are dark brownish red, but the large masses of broken rock below the cliffs are a much brighter red and give to the valley the appearance of being decorated with great red banners that are caught up at the base of the cliffs and stream down to the valley bottom in long, graceful curves. The walls are rugged and picturesque, but there is little or no variety, and one soon tires of watching the selfsame combination of river, talus slopes, and cliffs. The river, however, is really worth attention and presents many charming views of the clear water, almost turquoise blue, sweeping around willow-covered islands and between

the stately pines that dot the river's bank. . . . To the traveller interested in the geologic history of this region some of the most instructive features of this topography are small deltas or terraces in the side gulches at a height of fully 400 feet above the level of the track" (141, 142). I recognize fully the great value of the Railway Guidebooks as prepared by the Geological Survey, and recognize also that, at the present stage of geological investigation, a full knowledge of our vast Cordilleran region has not been gained—witness the interpretation here of side moraines as "deltas or terraces" already noted; but it may be suggested that observation of the "selfsame combination of river, talus slopes, and cliffs" will gain much interest to the traveller as soon as its meaning is pointed out: indeed, if the traveller is journeying eastward and watches understandingly the diminution and disappearance of the spur-end cliffs above Thompson Falls, and their replacement by subdued and waste-coverd valley-side forms of normal origin as he goes up the valley, the interest becomes absorbing.

Termination of Glacial Scouring.—A side stream, Camas creek, enters the main valley from the north by a narrow gorge, 13 miles above Paradise, and there lies the village embryo of Perma (2,511′); the creek drains part of an open treeless basin, a "camas" of the Indians, well occupied by farms; a large basin farther north but part of the same camas, with Camas for its chief town and a projected Camas canal in its irrigation scheme, is draind eastward by Little Bitterroot river which joins the Flathead some miles south of its lake. I had a general prospect over the Camas area from a fine lateral moraine, the largest example of its kind that I ascended, which forms a well defined embankment several hundred yards in length, and 500 or 600 feet above the stream, surmounting a low ridge of inclined and scourd ledges on the north side of the valley opposite Perma. Another embankment was noted on the upland about a mile to the north of the valley, suggesting a lateral extension of the valley glacier towards the Camas basin. The position and pattern of both these embankments seemd to me to preclude their having been formd by a glacier coming from the Camas basin on the north; they belong with scourd and clift spurs and salients of the valley sides as the work of a glacier that here ascended the valley and worked with decreasing intensity from Plains to this point and a little farther. Had the valley glacier been supplied from the Camas basin, its strongest erosiv work should be hereabouts, but that is not the case. Moreover, a waste-coverd spur sloping to the east, normally carved on rocks dipping to the west, was seen in profile beyond the farther one of the two embankments, and ript and notcht spurs were seen between the

two: hence the ice must have moved from the valley toward the Camas basin, as above stated.

On the south side of the valley at Perma the mountain side is scourd and ript, somewhat as in Fig. 13, but its slope is much less completely truncated than is usually the case near Paradise: curious channel-like chasms run irregularly along the ript slope, transverse to the spur-axis as if scourd out by ice along lines of weakness, or washt out by glacial-marginal streams. Ice-scouring is here the more probable process, because while the valley was occupied by the scouring glacier the valley sides should have been deeply submerged in Lake Missoula.

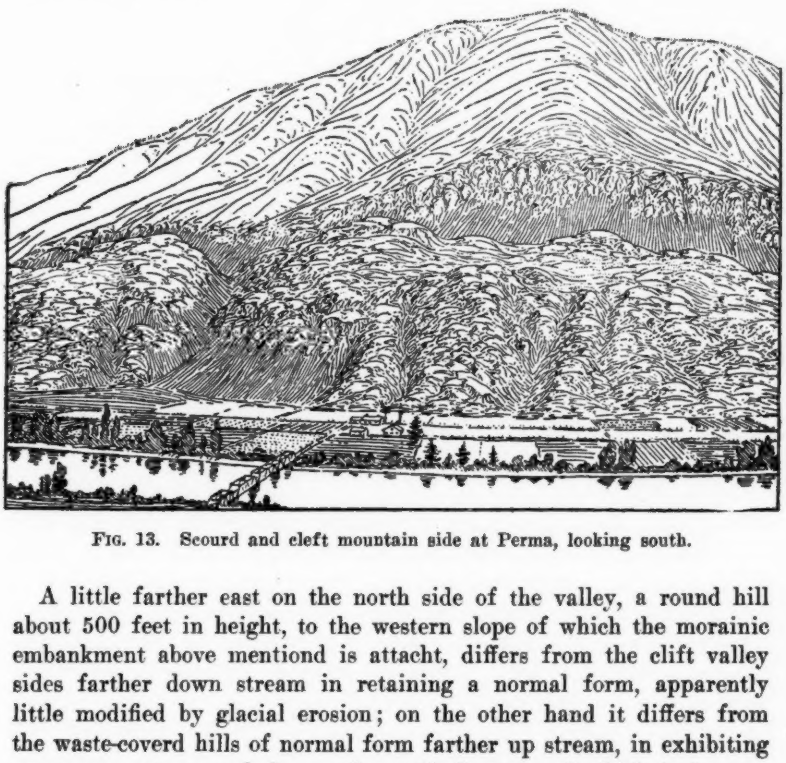

FIG. 13. Scourd and cleft mountain side at Perma, looking south.

A little farther east on the north side of the valley, a round hill about 500 feet in height, to the western slope of which the morainic embankment above mentiond is attacht, differs from the clift valley sides farther down stream in retaining a normal form, apparently little modified by glacial erosion; on the other hand it differs from the waste-coverd hills of normal form farther up stream, in exhibiting numerous outcrops of the nearly vertical strata of which it is composed. This hill is therefore interpreted as bearing the marks of light scouring by a glacier of small thickness, sufficient to remove most of the waste cover which such a hill should normally possess, but insufficient to destroy its general form. This is confirmd by finding that similar traces of glacial scouring on the lower slopes of

the valley sides continue for a few miles and that they gradually weaken and disappear six miles above Perma near McDonald station (2,518′).

Singular to relate, the limit of the glaciated section of the valley is not markt by any clearly defined terminal moraine: there are some large and softly molded hills in a valley-side embayment on the south near McDonald which may possibly be built of glacial deposits, but if so, their rounded forms suggest a much earlier origin than that of the small but well defined morainic embankments in the side valleys mentiond above. It is certainly remarkable that a glacier, of which the traces are seen in strongly clift valley sides farther down the valley, is not recorded here by abundant terminal deposits. Perhaps a reason for this may be found in the reduction of ice-pluckt blocks

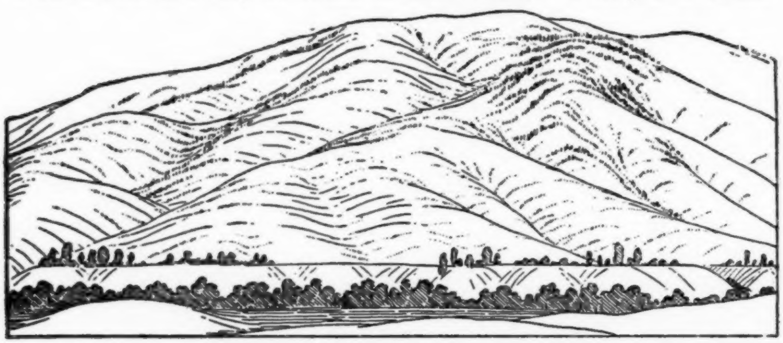

FIG. 14. Normal spurs and ravines at Dixon, near the junction of Jocko Creek and Flathead River, looking north

to fine sand and silt by long-distance scouring, and the removal of the sand and silt by sub-glacial down-valley currents. The vertical strata of the stript round hill seemd to be of slaty texture, and of less resistance than the quartzitic beds which form mountainous hills of greater height to the west. It is possible that the Camas depression on the north is to be ascribed, in part at least, to the more rapid erosion of the weaker slaty strata, which may there occupy a belt of greater breadth; but the manner in which the basin lies between the highlands, and especially the gentle declivity of the basin sides suggest that, like the larger depression which contains Flathead lake not many miles farther east, the Camas basin is chiefly due to the irregular down-warping—or failure of up-warping—of an old-mountain surface at the beginning of the current cycle of erosion rather than to erosion during the course of the cycle.

The Normal Valley of Jocko Creek.—After passing the last signs of light glacial scouring on the lower slopes of the valley sides

at McDonald, the railway ascends the valley 40 miles farther, and in this stretch, which is draind by Jocko creek above the entrance of Flathead river from the north, altho moderate variations of valley width occur, the valley sides show only normally carvd forms. Rock outcrops occur in the narrower gorges, but they are absent from the longer, maturely opend stretches. There the hills and spurs exhibit moderate variations of texture, shown in Figs. 14 and 15, but agree in possessing those smoothly graded slopes that are so significant of the long-continued action of the deliberate processes of weathering, creeping, and washing. A possible exception to this statement may be noted near Dixon where Flathead river comes in from the north. Here some hills rise on the south side of the valley like those above mentioned near McDonald, and may possibly be ancient moraines;

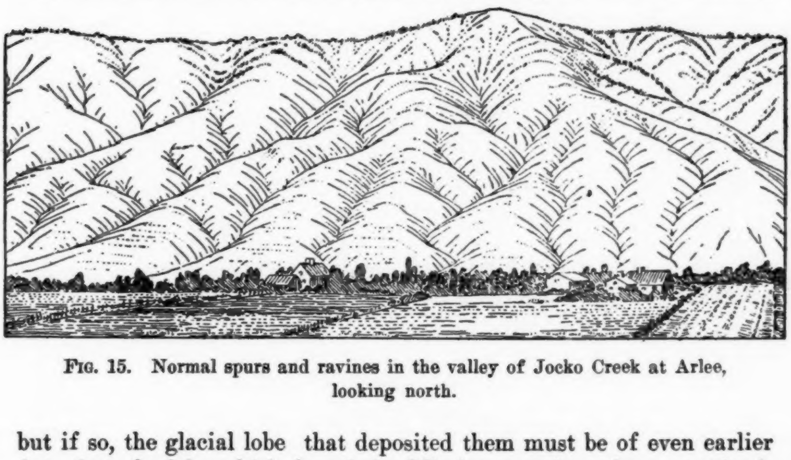

FIG. 15. Normal spurs and ravines in the valley of Jocko Creek at Arlee, looking north.

but if so, the glacial lobe that deposited them must be of even earlier date than the lobe which formd the Mission moraine, above mentiond.

The most significant feature of the normally subdued valley-sides is the perfect organization of their parts, whereby a delicate interdependence is establishd among all their many elements; this being an essential characteristic of a long establishd drainage system, as Gilbert first pointed out forty years ago in his classic report on the Henry mountains. Every element of the slopes is part of an elaborate system of down-hill lines, each of which begins in a convex profile above and descends to a concave profile below, and all of which unite in groups like the veins of a fern leaf along mid-rib lines, the mid-ribs in turn uniting in stronger lines, as in Fig. 15, and so on down to the main valley floor. The whole system of down-hill lines is developt in such a way as to dispose of creeping waste and running water in the most orderly fashion, so that their descent to the main valley shall be nowhere unduly retarded or hurried; and

all this evidently means the perfected accomplishment of a difficult task by the persistent, uninterrupted work of normal erosional processes, long continued without disturbance. When not alone the occurrence but also the meaning of these graceful forms is recognized, their increasing replacement by forms of an altogether different kind, as the valley is followd down stream, becomes impressively significant.

The heavy drift deposits in the valley of Upper Clark fork below Thompsons Falls have already been mentiond. From that point farther up stream, the valley floor is aggraded but the depth of its filling is not known as it is generally but little terraced, except in the backhanded turn near St. Regis. After the signs of glacial erosion are past at McDonald, the valley filling is trenchd to a depth of about 100 feet, and the terrace scarps thus formed consist of bedded silts, presumably of lacustrine origin; farther up stream, the trenching is less deep.

Source of Ice in Upper Clark Fork Valley.—The lateral cliffs in the valley of Upper Clark fork, above described as due to glacial erosion, may be reviewd with the object of discovering the possible sources of the glacier or glaciers by which the valley was invaded. It was suggested in the introduction to this essay that the invading glacier was a single, long, narrow distributary of the great Kootenai-Pend Oreille glacier, but the objections to such a single source presented by my censor seem valid and are here accepted; except that a short stretch of the valley up-stream from Pend Oreille lake was probably invaded by a distributary glacier thus supplied. A longer stretch of the valley for some thirty or forty miles above the probable end of this distributary has not been examind closely enough to determin surely whether it was glaciated or not: local glaciers from the Cabinet mountains may have reacht this stretch. The first indubitable signs of glacial action are found in the broad moraine that obstructs the valley by Thompson Falls, but the direction from which a glacier advanced to lay down this moraine was not learnd. No open entrance for a glacier from the north was here observd. Strong valley-side cliffs are found in the Woodin-Weeksville narrows between the Thompson Falls and the Plains basins; and again above the Plains basin in the Paradise district, beyond which their strength gradually decreases until all signs of glacial erosion disappear at McDonald in the Flathead extension of the Upper Clark fork valley. As the Thompson Falls basin seemd to be closed on the north, while the Plains basin is open for a considerable distance in that direction, it appears possible, as already briefly noted, that a glacier from the Cabinet mountains, advancing thru the Plains basin into Clark fork

valley, there brancht up and down stream and was responsible for the cliffing of the valley sides. After eroding strong cliffs in the narrows below Plains, the down-stream branch may have expanded so greatly in the Thompson Falls basin as to do little erosional work on the basin sides, altho it there, nearly twenty miles from its entrance, seems to have deposited a large moraine at the far end of the basin as the product of erosional work farther up its course. Similarly, an up-stream branch of an invading Plains glacier, after strongly cliffing the valley sides in the Paradise district and sending off a short back-handed branch toward St. Regis, gradually weakend toward Parma and disappeard at McDonald in the Flathead extension of the Upper Clark fork valley, nearly 20 miles above Plains.

There appears no possibility that an actively eroding glacier could have recently reacht the Paradise district from the upper Flathead or Jocko valley; first, because there are no lofty mountains near by to supply it; second, because the farthest recent advance of the great Kootenai-Flathead glacier into the Flathead basin did not reach nearly so far south as the Jocko valley; third, because the valleys in question bear no signs of recent glacial erosion above McDonald. The uppermost valleys of Clark fork, much farther east and south, were glaciated only near their heads. No ice could have possibly reached the Paradise district from those distant sources.

A stretch of country from the Plains basin northward to the Cabinet mountains probably contains the clue to the correct solution of the problem here outlined. A study of its glaciation would be repaying.

THE SHORE LINES OF LAKE MISSOULA. *General Features of the Shore Lines.*—The delicate horizontal benches that may be seen faintly contouring the smooth grassy slopes of many graded hills and mountains by which the basin of Upper Clark fork and its branches is enclosed, and that are particularly well shown on the mountain sides directly east of Missoula, north and south of the deep Clark fork notch, have been recognized as lake shore lines by many observers, but little has been publisht about the origin of their lake, to which the name of Lake Missoula has been given. The best description of the shore lines is by Pardee,[18] who gives also a summary of earlier observations and presents sound reasons for regarding the lake as bard by a heavy glacier which occupied Clarks fork valley near the north end of Lake Pend Oreille. A later general account of the Missoula shore lines and terraces is given in the Guidebook of the Northern Pacific Route: it closes with the statement:—" There seems to be a gradual decrease in the altitude of the terraces toward the northwest

[18] T. J. Pardee, The Glacial Lake Missoula, *Jour. Geol.*, XVIII, 1910, pp. 376-386.

that indicates a depression in the earth's crust in that direction since the beaches were formed, or a rise in the surface toward the southeast" (136). This opinion seems to me open to question, and it should remain so until exploration has been carried to much greater detail than it has yet reacht. None of the accounts of Lake Missoula make mention of the spur-end cliffs along the sides of Upper Clark fork valley as a result of erosion by the glacier that bard the lake.

The shore lines are so faintly markt that they are better seen at a distance of half a mile or more than near at hand. Instead of possessing nearly a vertical cliff rising at the back of a nearly horizontal bench, such as may be seen in the wave-cut shore lines of existing lakes, they show only a slight steepening and flattening of the soil-coverd slopes on which they are engraved. They are 10, 20 or 30 feet apart, and may sometimes be counted, one over the other, to the number of 20 or 25. They are by no means continuous; indeed it is surprising to note how arbitrarily they are distributed; for they are often imperceptible on bare rounded spurs, not far distant from smoother valley sides on which they are plainly visible. Where well developt, as on the northern slope of the subdued hills between the Flathead depression and the valley of Jocko creek, a down-hill line, tangent to the salients of the benches, would pass only from two to five feet outside of the reentrants. The visibility of the shore lines varies greatly with the relation of sunshine to the hillside aspect; they are said to be best seen after the partial melting of a light fall of snow. They never slant and branch after the manner of cattle tracks; it is their apparent horizontality and their exact parallelism when seen from a distance, that convinces the observer of their lacustrin origin.

The best series of shore lines that I examined by walking over them was on the northern slope of the subdued quartzite hills that form the southern boundary of the Flathead depression, separating it from the valley of Jocko creek. The position of the shore lines here made it manifest that the whole of the great depression, except so far as it was then occupied by the heavy ice of the Kootenai-Flathead glacier in the north, must have been deeply submerged in the lake waters. Occasional large erratic boulders, presumably ice-rafted to their present position, lie on these shore lines at various levels. In a notch in the hills, where a road passes from St. Ignatius to Ravalli on Jocko creek, a broad bar, Fig. 16, seems to have been formed by ice-rafted detritus.

Extent of Lake Missoula.—At the time of its greatest extent, when the surface of Lake Missoula reacht 4,200 feet altitude, it must have occupied a large area in the valleys of Upper Clark fork

and its branches, of which the chief are:—the broad Flathead basin on the north at least as far as the Polson moraine, the smaller Camas basin next west, and the valley of Jocko creek next south, the Bitterroot valley south of Missoula, the Blackfoot valley east of Missoula, and the short valley of St. Regis river west of the village of that name. The extreme length of this ramifying water body, from northwest to southeast, must have been over 150 miles. Its maximum depth at McDonald in the Flathead-Jocko extension of Upper Clark fork valley must have been 1,700 feet, as will be more fully shown below. A rough outline map of the lake is given in a figure opposit page 144 of the Guidebook to the Northern Pacific Route. Much detaild exploration will be necessary before the distribution of observable shore lines can be recorded, and until topograhic maps of all the region

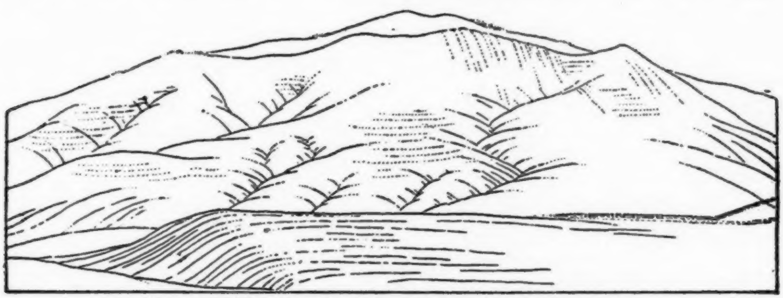

FIG. 16. Flat-floord notch near Ravalli, looking west.

concernd are publisht this exploration will probably not be undertaken; even then the detection of shore lines on forested slopes will be difficult if at all possible. On the other hand, the extent of the lake at its highest stage over all parts of the region where the altitude is less than about 4,200 feet cannot be doubted after the well defined shore lines at those altitudes near Missoula and elsewhere are recognized.

Section of a Shore Line.—Near the end of my excursion, I selected one of the best defined shore-line benches in the upper continuation of the Flathead-Clark fork valley, draind by Jocko creek, in which to have a trench cut so as to examin the bench structure. The locality of the cut is 15 miles southeast of the entrance of Flathead river from the north, on the southwest side of the valley near the village of Arlee on the Northern Pacific railway, where the hills are well graded in spite of their being composed of resistant quartzitic sandstones in inclined position. The trench was cut with proletariat aid to a length of about 15 feet and a depth of three or four feet; it disclosed a cover of brownish soil, with plentiful angular scraps of local sandstone

and occasional rounded stones of foreign origin; beneath this lay some two feet of well rounded cobbles, chiefly of local origin, coated with a gray calcareous incrustation. Unfortunately the time allowd for this work was too short to complete the trench down to bed rock and across the bench to its cliff, but the cutting sufficed to indicate that the benching of the slope had been originally much more distinct than it is now, and that creeping soil has largely obliterated the forms left by the waves. It would be well to have this conclusion confirmd by cuts in other benches.

The Lake Missoula Ice Barrier.—It may be reasonably inferd from these observations that Lake Missoula fluctuated in level without long remaining at any one height. The lake must be of late glacial or of postglacial date, because the shore lines are traceable on the southern or outer side of the great Polson moraine and on some of the piedmont moraines formed by local glaciers of the Mission range not far from St. Ignatius. Of these two dates the former is much more probable, because no postglacial barrier can be imagind to hold back the lake waters, while the well proved branch glacier which invaded Upper Clark fork valley next above Pend Oreille lake, or a glacier of more local origin farther up the valley, must have formd a barrier of satisfactory duration and strength. All the lakes of this region now overflow; hence in the cooler climate of the glacial period, Lake Missoula also must have overflowd. The fluctuation of lake level must therefore be interpreted as indicating a corresponding fluctuation in the height of the lake outlet; hence the outlet was probably across an ice barrier, or along the depression between the southward slope of an ice barrier and the northward slope of the adjoining mountains. A similar interpretation has been proposed for lakes recorded by faint shore lines at many levels in Scandinavia. The duration of the lake was longer than would be inferd at the first sight of its faint shore lines; for the benches were originally stronger than now, and they would have been stronger still if the country rock had not been so generally resistant and if the attack of the waves had not been distributed at many different levels. During the winters of the glacial period the lake was probably frozen over; during the summers, some of its bays and branches, especially those opening to the west, may have borne much floating ice; and both these conditions would have weakend wave work.

Probable Barrier and Outlet near Lake Pend Oreille.—Lake Missoula must have had its ice barrier and outlet either where the great Kootenai-Pend Oreille glacier abutted against the northern slopes of the mountain masses on which the southern distributaries of the

glacier were divided at the northern end of Lake Pend Oreille; or farther up Clark fork valley, probably near the Plains basin, where the valley seems to have been invaded by a local glacier from the Cabinet mountains. The first of the two locations seems the more probable because of the great thickness of the Kootenai-Pend Oreille glacier at that point. The barrier, if there, was probably on the eastern side of the lake, as Pardee has shown, for the mountain slope on that side of the lake basin, where the valley of Upper Clark fork joins it, is higher and steeper than on the western side. This location for the ice barrier is accepted in the U. S. Geological Survey Bulletin on the Northern Pacific Route (135). The ice must have been very thick here, for Calkins has traced marks of glaciation on the mountains a little farther north to a height of 2,500 feet above the lake, or 4,500 feet above sea level.

Further reasons for locating the ice barrier and outlet of Lake Missoula between this mountain slope and the abutting ice at the northeast end of Lake Pend Oreille are:—Even the lowest passes in the mountains at the distant headwaters of the Clark fork system, far to the east and south, are much higher than the level here reacht by the abutting ice. A northern escape for the lake waters must have been prevented by the great Kootenai-Flathead glacier which filld the depression between the Rocky Mountains and the Flathead-Cabinet mountains. The level at which the great Kootenai-Pend Oreille glacier abutted against the mountain mass between Clark fork valley and Lake Pend Oreille, as indicated by the upper limit of the oversteepend mountain-side slope, is between 4,000 and 4,500 feet, while the highest shore line is about 4,200 feet. Hence the outlet of the lake would seem to have followd the channel here defined by the southern slant of the ice surface against the northward slope of the mountain. Just as a southward distributary of the great glacier followd a valley which is now overdeepend in the trough of Lake Pend Oreille, so the southeastern distributary must have advanced a certain distance up the valley of Clark fork and overdeepend it; but this overdeepening is now counterbalanced by postglacial aggradation. How far it extended and to what degree it was accompanied by oversteepening of the valley sides remain to be determind.

It is unfortunate for my record that this location of the barrier was not defined during my excurison, for the base of the mountain concernd is only a mile from Clark Fork station of the Northern Pacific railway. The northern end of the mountain rises, according to the topographic map of the Priest Lake quadrangle, boldly in an oversteepend slope from the lake (2,051′) to an undulating crest in which the knobs range from 4,200 to 5,200 feet, and the notches from about 3,900 to 4,400 feet; two ravines a mile back of

the ridge open to the east and west; the lowest point in the divide between the ravines is about 4,200 feet, and to the south of this point the mountains soon rise above 6,000 feet. The divide at 4,200 feet is therefore a possible location for a short-lived highest overflow of Lake Missoula. During the rise and fall of the lake, its outlet must have been along the oversteepend slope of the northern ridge at many different levels. The sloping mountain side should therefore be searcht for bared, water-worn rock surfaces, associated with channels, potholes, and plunge-pools on salients at various levels, and adjoind by beds of boulders and gravels that may have been washt into the slopes of any reentrants.

Further signs of rushing waters should be lookt for on the mountain slopes that enclose Lake Pend Oreille on the east; they should be absent along the southeastern side of the basin where a small, independent proglacial lake must have occupied the normal, non-glacial valleys of the two Gold creeks that come from the Coeur d'Alene mountains; but they should begin again on the mountain slopes, beneath Bernard peak of Chilco mountain, that enclose the southwestern arm of Lake Pend Oreille on the south; except that here, as well as on the eastern side of the lake, the oversteepening of the mountain side by glacial erosion may have removed all traces of channels cut by the Lake Missoula outlet during the waxing phase of the glacial invasion; and that the walls thus oversteepend would not be well shaped for the erosion and preservation of outlet channels during the waning phase. The final discharge of the outlet must have been upon the great gravel plain that stretches from the moraine at the southwestern end of Lake Pend Oreille to Spokane and beyond: the discharge on the plain should be indicated by an abundance of boulders, brought from the ice or dislodged from the mountain side; the lake water here must have given helpful reenforcement to the sub-glacial waters that rose from beneath the Pend Oreille glacier; the latter were presumably well charged with detritus; the former must have been comparatively clear.

A Possible Lake Barrier in Upper Clark Fork Valley near Plains.—Altho the most probable location for the ice barrier of Lake Missoula appears to have been at the northeast end of Lake Pend Oreille, it is desirable to consider an alternative possibility; that of a barrier formd by a Cabinet-mountain glacier which filled the Plains basin and, abutting against the southern side of the Clark fork valley, sent out its inferd branches up and down stream. The altitude reacht by such a glacier is unknown; the relation of the time of its maximun advance to that of the much larger Kootenai-Pend Oreille glacier is undetermind. One may therefore conceive that, even if

the greater glacier for a time formd a lake barrier farther down Clark fork valley, the smaller glacier may have, earlier or later, formed an independent barrier at Plains. But the lake shore lines on the hills near Plains are manifestly against the possibility that the Plains ice barrier was of later date than the barrier farther down the valley; for when those shore lines were formd the Plains glacier must have withdrawn, altho the barrier farther down the valley was still present tho perhaps not at its highest level. If the Plains glacier withdrew from the Clark fork valley and the Plains basin sooner than the greater Kootenai-Pend Oreille glacier withdrew from the same valley farther down stream, then it is probable that the Plains glacier enterd the valley later than the greater glacier. Thus interpreted, its invasion of the valley was probably during the maximum stage of the greater glacier and therefore during the highest stage of the lake. Hence, unless the Plains glacier was strong enough to form a higher barrier than the one at Lake Pend Oreille and thus divide an upstream lake of greater altitude from a down-stream lake of less altitude, it must have been simply an invader of a continuous lake. Whether, as an invader, it crept along the lake bottom and was submerged beneath the lake surface, or whether it was floated up and more or less disintegrated by the lake waters, remains to be determind. This question will be examind in a later section.

The Deltas and Sediments of Lake Missoula.—As the Kootenai-Pend Oreille glacier advanced across the valley of Upper Clark fork, where that river reaches the northeastern arm of the present Pend Oreille lake, the river must have been displaced southward to the foot of the adjacent mountain; and thereupon Lake Missoula began to form. As the ice advanced farther and higher and its southern and southwestern arms were divided, the lake also rose higher, and thereupon deltas must have begun to form where the shortend course of Upper Clark fork enterd the lengthening lake; and as each delta advanced a little, all the valley floor farther upstream, as far as it had been previously graded, would then be aggraded. With still greater advance of the ice, as many of the lake deltas as were reacht and overridden by the branch glacier that entered Upper Clark fork near Lake Pend Oreille, or by a more local glacier farther up the valley, must have been scourd away; but beyond the farthest advance of the glacier the deltas might remain on the lake bottom, and merely suffer terracing after the lake fell and the river was reestablisht. The heavy terraces, which occupy part of the backhanded turn of Upper Clark fork valley below St. Regis, are probably of this origin; their coarse gravels must have been deposited either before or after a short branch glacier enterd the backhanded turn from its end

near Paradise at the time of greatest glacial advance, because when the ice was there the lake must have have been at its highest level, or over 4,000 feet altitude, and St. Regis would then have been submerged under 3,000 feet of lake water. On the other hand the delta which was formd by Upper Clark fork when the ice had its greatest advance ought to be as high as the highest lake shoreline and should therefore be searcht for much farther up the valley; the remnant of such a delta is probably to be found some 60 miles southeast of Missoula, a little distance above Gold Creek station (4,201′) of the Northern Pacific railway, where a long gravel terrace, about 40 feet over the river, was noted from a passing train. Similar terraces should be searched for in the Blackfoot and Bitterroot valleys.

The gravel of the St. Regis terraces should not be regarded as having been supplied by the outflow of water from an advancing branch glacier in the backhanded turn of Clark fork valley; first, because no similar gravels are found at the end of the glacier in the Flathead valley between Perma and Dixon; and second, because it is not likely that any concentrated stream ran out from the end of the glacier, for the glacier then terminated in the standing waters of Lake Missoula, and the discharge of the lake was 100 miles back of this ice end; hence there was probably no concentration of a discharging underflow stream beneath the ice, and no ice cave at the above noted glacier ends. The water melted from this part of the invading ice must have tended to find its way back toward the lake outlet. In view of the strength of the St. Regis terraces of Clark fork, it is curious that no similar terraces were formed by Flathead river, just below its elbow, when the lake stood at an altitude of about 2,600 feet; perhaps this is because the detritus from most of the Flathead headwaters was deposited in Flathead lake.

During the higher stands of Lake Missoula fine textured silts would be spread over the deeper parts of its bottom; they would be washt and trencht by extending streams as the lake fell. The gray silts now seen in many valley terraces, as at the outlet of Flathead lake by Polson and at the river elbow by Dixon, are apparently of this origin. The gravel that is strewn on some of the silt terraces probably represents river work as the lake was waning.

Disappearance of Lake Missoula.—During the fall of Lake Missoula, delta growth would take place on top of the lake silts at each pause, with corresponding aggradation of graded upstream stretches; and the whole series of deposits thus formd would tend to become confluent along the valley floor, or to be more or less terraced as the lake finally disappeard. Thus the valley of Upper Clark fork, for some miles below the backhanded turn where Flat-

head river joins it, has a flat floor; at Paradise, a mile below the turn, a well from which the railway water tower is supplied penetrated gravel for 30 feet without reaching rock. In the two basin-like expansions of the valley farther down stream, one at Plains, the other at Thompsons Falls, the valley floor is broadly aggraded and moderately terraced. Then for many miles down the valley, below the Thompsons Falls moraine, the valley floor is occupied by an aggraded gravel plain and the plain is trencht to depths of from 30 to 70 feet. Terraces are abundant here; rock knobs occasionally rise thru the terrace plain, and the river is sometimes locally superposed on nearly buried rock ledges, producing gorges and falls, as has been briefly stated on earlier pages.

Relation of Clark Fork Glaciers and Lake Missoula. *Assumed Synchronism of Glaciers and Lake.*—The conditions under which the side slopes of Upper Clark fork valley were scourd and clift remain to be examined. It has been made plain that, according to the best determination I could make on the ground, the scouring and cliffing were done by glacial ice; and that, adopting the suggestion of my censor, the ice presumably enterd the valley at more than one point in the form of several separate glaciers, after river erosion had given the valley a normal form essentially similar to that which it still exhibits in the non-glaciated headwater stretches. Now if the invading and eroding glaciers were synchronous with the great glacier that held up Lake Missoula at the head of Lake Pend Oreille, and therefore with the lake itself, it follows that the erosion of the valley-side cliffs must have been done at a considerable depth beneath the lake surface. In the Woodin-Weeksville narrows and in the Paradise district, the valley-side cliffs truly have a height of several hundred feet; but the aggraded valley floor over which they rise there stands at an altitude of only from 2,400 to 2,500 feet; while the highest lake shore line stands at 4,200 feet. Even if the region has been tilted since the lake disappeard, so that the highest shoreline hereabouts should stand at about 3,500 feet, the valley floor would have been at a depth of 1,000 feet in the lake waters. If no recent tilting has taken place and if the eroding glacier in this section of the valley really had its greatest size when the lake stood at its highest level, the base of the glacier on the rock bottom of the valley must have been about 2,000 feet below the lake surface; and the surface of the glacier near its up-stream end must have been under some 1,700 feet of lake water. This would certainly be a surprising relation of ice and water; yet the progress of the history of the problem of glacial erosion seems to give it some support, as the next paragraph will show.

Progress of Views on Glacial Erosion.—When the former existence of great valley glaciers in various mountain regions was first recognized over eighty years ago, the share that the glaciers had in eroding the valleys was not particularly considerd; indeed, at that time the origin of mountain valleys by erosion of any kind was not well assured. Some twenty-five years later, when Ramsay suggested that the piedmont lake basins of the Alps had been excavated by glaciers, he gave little or no attention to the erosional origin of the valleys upstream from the lakes. In the following years, when fiord valleys were attributed to glacial erosion by some daring theorists, it was more or less tacitly assumed that the erosion had been accomplisht while the land stood higher than now, and that the glacial troughs were invaded by sea water only after a postglacial subsidence. However, further consideration of this question led to the view that large glaciers might deepen their troughs somewhat below sea level; but that, the deeper their beds were eroded, the more their ice would be buoyed up by sea water, and the slower their further erosion would be. Gilbert went a step beyond when he pointed out that large glaciers press so heavily upon their beds that sea water may hardly find its way beneath them to buoy them up, and that they would therefore, even after excavating their troughs to a considerable depth beneath sea level, still press downward with their whole weight and continue their erosional work effectivly. Under this view, the depth to which a fiord glacier could erode its trough would depend chiefly upon a reduction of its velocity as a consequence of an increase in the cross-section of its trough, rather than upon its relation to sea level.

A final step in this progressive change of views would be taken if it should become necessary to recognize, in such cases as that of Clark fork, that glaciers may continue, even after they are wholly submerged, to erode the bed and sides of their troughs. There can be no question, however, that such a conclusion should be regarded as extremely doubtful until its acceptance is compelld by convincing evidence. Hence it is desirable to inquire particularly into the possibility of explaining the peculiar erosional features of Clark Fork valley in some other way than by the action of a submerged glacier.

The Lake Missoula Shore Lines may Antedate the Valley-side Cliffs.—The supposition that the valley-side cliffs of upper Clark Fork valley were eroded by a wholly submerged glacier is so inherently improbable and the mechanical difficulties that it involves as pointed out by my censor are so serious, that notwithstanding my acceptance of this supposition in a brief earlier essay,[19] an alter-

[19] Sublacustrine Glacial Erosion in Montana, *Proc. Nat. Acad. Sci.*, III, 1917, pp. 696-702.

nativ for it must now be examind; namely the possibility that the eroding glaciers of Clark Fork valley were not synchronous with the existence of the high-level stages of Lake Missoula.

It has already been stated that both of the great Canadian glaciers here considerd appear to have had epochs of farther extension markt by their more advanced moraines, and of less extension marked by less advanced moraines; and it is possible that these two epochs may have corresponded to the Illinoian and Wisconsin epochs of Glacial chronology. Let it now be supposed that while the Kootenai-Pend Oreille glacier made its greater advance and formd the heavy moraines at the southern end of Lake Pend Oreille, is servd, as already noted, as a high-level barrier across Upper Clark fork valley which was therefore filld with Lake Missoula. Let it be further supposed that the southeastern distributary of the Kootenai-Pend Oreille glacier was shortend by flotation in the deep lake waters so that it invaded Clark Fork valley for a relativly short distance. Also, that any glaciers which in that epoch reacht the lake from the Cabinet mountains were likewise broken up by flotation shortly after they enterd the lake waters and before they reacht Clark fork valley. Evidently the lateral cliffs of Clark fork valley could not have been eroded under these conditions. Farther east, in the Flathead basin, the Kootenai-Flathead glacier may have had thickness and weight enough not to be floated and broken up until it reacht the Mission moraine.

Now let the glacial conditions during the formation of the later moraines be considerd. In that epoch the Kootenai-Pend Oreille glacier is thought to have ended at the Elmira divide between the Clark fork and the Kootenai drainage basins. When it was thus situated, it would not have held back any lake in Upper Clark fork valley; and the local glaciers from the Cabinet mountains might then, not being broken up by flotation, have advanced farther than before, even tho glaciation in general was less severe. One or more such glaciers might under these conditions have reached Clark Fork valley where they would proceed to scour and cliff the side slopes in adapting the form of the valley to their needs.

So far as a right-hand or down-valley distributary of a possible Cabinet-mountains glaciers in Plains basin is concernd, no special difficulty arises regarding its erosion of cliffs in the Woodin-Weeksville narrows, for it need not have encounterd a lake there, unless one was formed by another Cabinet-mountain glacier farther west. But if the Plains glacier could send out a right-hand distributary several miles in length, it must have formd a strong barrier across Clark fork valley in the Plains district, and thus have held up a good-sized lake in the Paradise district and farther up stream: and the left-

hand distributary of the Plains glacier, by which it is here supposed that the cliffs of the Paradise district were scourd off, must have been more or less submerged in this lake. This would be particularly the case towards the up-stream extremity of the glacial distributary near Parma, where the valley floor is much below the top of the cliffs above Paradise, and hence much more below the barrier that the Plains glacier must have formd across the Clark fork valley. Hence while the suppositions here set forth diminish the difficulties that were encounterd in the preceding section, they do not dispose of them altogether. Some sublacustrin glacial erosion still seems to be demanded.

As complete escape from the necessity of assuming at least a certain amount of sublacustrine glacial erosion is not provided by the above suppositions, it is worth while to inquire into the possibility of a valley glacier holding itself in a valley bottom beneath the waters of an ice-barrier lake. If the ice front in such a lake were broad and free, the opportunity for its flotation would be increasd; but if only a narrow valley glacier is concernd, the manner in which it would wedge its way along the valley suggests that friction with the valley sides might seriously impede its flotation. The more the two valley sides were clift, the stronger would be the friction-hold on the ice between them. On the other hand, the presence of water above the ice would tend to counteract pressure from thicker ice in Plains valley, and thus to retard if not to prevent the advance of the ice-distributary up stream. As to this point, all I can say is, that if no lake had been there, the distributary might have had a greater length than the 20 miles from Plains to Parma. An up-valley advance for such a distance would be singular enough, even if no lake were present to impede it, but it would not be so forbiddingly extraordinary as an up-stream advance for 100 miles, as I had previously supposed to be necessary when the ice supply was assumed to come from the Kootenai-Pend Oreille glacier. Regarding the fact of an up-stream advance of 20 miles, that is no more than was accomplished by many an Alpine valley glacier as it emerged from a piedmont lake basin to its terminal moraine.

It will be a matter of interest to follow the results of future studies in this region, with special regard to the modifications that they demand in the views here set forth. In that connection it is desirable to state explicitly that the Plains glacier, to which reference has been repeatedly made on preceding pages, following the general suggestions of my censor, is at present altogether a hypothetical affair. Certification of its former existence would be gratifying; if proved, it might be well named after the anonymous prophet of its existence, if his name can be divulged by the Editor of the *Annals*. Other matters to which attention may be well directed are:—The indications of lake dis-

charge on the mountain slope that occupies the angle between Upper Clark fork valley and the trough of Lake Pend Oreille; the maximum height to which lake shore lines are found hereabouts and on the mountain sides to the southeast; the distance to which signs of glacial erosion are found in Upper Clark fork valley up stream from the lake; the nature of the Elmira divide between Clark fork and Kootenai drainage basins.

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Volume X, pp. 149-152

MEMOIR OF FREDERICK VALENTINE EMERSON

ALBERT PERRY BRIGHAM

Our departed fellow worker and friend was born in Tillotson, Pennsylvania, in 1871 and he died in Baton Rouge, Louisiana, in October, 1919. Emerson was reared to farm life, but early developed his love of books and study. In the face of some difficulty, aided by the sympathy of a discerning mother, he entered upon a high school course. After a period of rural school teaching he pursued further studies in the normal school at Edinboro, Pennsylvania, where an acquaintance turned his interest toward Colgate University, from which he was graduated as a Bachelor of Arts in 1898. His modesty, earnestness and careful scholarship were, as in all later years, marked characteristics of his life in college. He elected no work in earth science until his Senior year began, but during that year he pursued all the courses that were open to him. He had intended to become a chemist, but a new interest seized his thought, stirred his imagination, and held him unwaveringly to the end of his life.

After graduation he engaged in high school teaching during a period of four years, at Warren, Steelton and Ardmore, Pennsylvania. As his interest grew and the way opened, he turned toward graduate study, becoming Assistant in Geology in Cornell University in 1903-1904, scholar in geology at Harvard University in 1904-1905, and fellow in geography and geology in the University of Chicago in 1905-1906. He received the degree of Doctor of Philosophy from the University of Chicago in 1907, his thesis dealing with the theme, "A Geographic Interpretation of New York City."

Professor J. Paul Goode writes that Dr. Emerson took the first degree in geography given in any American University. He was the only candidate for the degree in the department at Chicago at that time. Dr. Goode says further of him, "he was an ambitious student, with an insatiate appetite for work. He was enthusiastic in his conception of the great place the science should take in a liberal education and was anxious to contribute to the development of the field. He was courteous and sympathetic in his relations with others and the difficulties he overcame in getting his own education made him generous and helpful to the students who later in large numbers attended his classes."

During the summers of 1905 and 1906 he was an instructor in the summer school of the University of Missouri, a service which led to his appointment as instructor in geology in that institution in

the latter of those years. He had already had experience of summer school work in Cornell University, and had thus come into contact and sympathy with the work and needs of teachers of geography in the lower schools.

In going to the University of Missouri, his varied training in the earth sciences, his quiet but unquenchable enthusiasm and his experience as a teacher in secondary schools, added to teaching at Cornell and Chicago, all fitted him to enter fully into a large opportunity. Dr. C. F. Marbut, the head of his department in this period, says of him, "His chief characteristics, as I look back over his work while we were associated together were, patient, persistent, untiring effort, sustained by an absolutely unvarying devotion to his work. In his teaching he was thorough, never depending on unsupported generalities. He never entered his classroom without being fully prepared. He never undertook a piece of work without giving to it the best he had in him. He was conscientious almost to a fault."

In 1913, Dr. Emerson was made a member of the Sigma Xi fraternity by the chapter in the University of Missouri.

In 1913, Dr. Emerson was appointed Professor of Geology in the State University of Louisiana at Baton Rouge, in which he remained to the time of his death. Here he made a large place for himself, by the force of his scientific training, by his sincere, friendly and generous personality and by his unselfish devotion to the progress of his students.

I cannot otherwise so justly convey to the Association of American Geographers, the regard in which our late co-worker was held by his colleagues in Louisiana, as by quoting from a letter received from a fellow member of the University Faculty. "I never knew a more delightful man. He had a charming personality and everyone who knew him liked him. His students say that he was one of the best teachers on the faculty. They felt that he had a scholarly grasp of his subject and that he presented it in a remarkably clear and forceful manner. They realized too that he took a personal interest in them and in their work. He often had personal conferences with his students and they felt free to call upon him for help and advice at any time. I know of no one who was more genuinely loved by his students."

The Louisiana Faculty in its memorial action after Emerson's decease, recognize his fine qualities both as a man and a scholar, his innate modesty, his sympathetic qualities as a teacher, and his productive scholarship.

Throughout the period of his service in the University, he was connected also with the Experiment Station, and as head of the state soil survey he performed a large amount of field service and

issued several bulletins giving results of the work. He gave considerable effort in war service and spent much time at the beginning of the war in the writing of a report on road building materials for the Council of National Defense.

Dr. Emerson held his official titles and did much of his teaching and investigation in the field of geology, but his deepest interest seems always to have lain in the realm of human geography. He was through and through a geographer of the modern type, and his chief delight in his exact and thorough studies on the physical side of his science, was to trace the influence of these material factors upon the life and activities of man. This is evident through a glance at the titles in the subjoined bibliography.

Some of his geographic papers he read at meetings of the Association of American Geographers. He also published a very full and useful laboratory manual of physical geography which presents a vast body of serviceable help and suggestions drawn largely from studies of the topographic map of the United States.

He left at the time of his death, the manuscript of an important volume, bearing the title—"Agricultural Geology." This volume has now appeared and its publication gives satisfaction to all his friends and to all who are interested in this field of earth science. It was illustrated and put through the press by Mrs. Emerson in a manner which held true to all of its author's habit of careful scholarship and exacting thoroughness.

Professor Emerson's going carries with it the loss of a quarter of a century of geographic enrichment which might have been expected could his life have been prolonged.

He lived an ideal life in his home relations, the circle including his wife, a daughter and a son. Mrs. Emerson was a teacher before their marriage, and she was his intellectual companion, his critic and comrade in all his work. In his death our ranks are broken, in the loss of a gentle friend, a helper of young men, a tireless student, and a geographer who dwelt in the heart of the science and had vital convictions of its meaning and value.

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St. Louis, 1919.

Charles Redway Dryer.

Presidential Address:—Genetic Geography; The Development of the Geographic Sense and Concept;—Printed in full herewith.

Isaiah Bowman.

Memorial of Theodore Roosevelt.

Albert P. Brigham

Memorial of Frederick V. Emerson;—Printed in full herewith.

Fred J. Breeze (Introduced by Charles R. Dryer.)

Southern Indiana;—A Regional Study.

The regional study of southern Indiana on which progress was reported is essentially a study of physiographic influence; or in other words, it is a quantitative study of the economic responses that man has made to the physical environment.

Southern Indiana includes the unglaciated portion of the state, the areas of Prewisconsin drift on each side of the unglaciated tract, and the margin of the area of Wisconsin drift border has been largely determined by geologic structure—A succession of thick series of hard and soft rocks, which dip gently to the southwest, gives rise to seven physiographic regions which trend roughly north and south. Each of these areas is different from the others in topography, soils, underlying bedrock, and other physiographic features. Because of the physiographic influences upon human economics, each of these belts is also a distinct economic region. These afford splendid opportunities for studies in geographic contrasts.

Stephen S. Visher (Introduced by Charles R. Dryer.)

Regional Geography of Southern Wyoming.

W. H. Haas (Introduced by H. H. Barrows.)

Physical Environment of the Cliff Dwellers of the Mesa Verde.

C. J. Posey (Introduced by R. H. Whitbeck.)

Regional Geography in Minneapolis—St. Paul.

The great northwest with its invigorating climate and with its resources of fields, forests, and mines furnishes an ample hinterland for the rise of a large urban center whose immediate location is determined by the falls in the great river which taps this hinterland. This site, moreover, is a natural focal point for present day lines of

commerce. The rapid and substantial growth of Minneapolis-St.Paul is, therefore, a true geographic expression of the development of the northwest.

J. Russell Smith.

A Proposed Division of North America into Economic Districts on Natural Regions—Read by Title.

Charles C. Colby (Introduced by H. H. Barrows.)

Commercial Divisions of the World.

Wellington D. Jones (Introduced by H. H. Barrows.)

Geographic Regions and their Subdivisions as Illustrated by China.

Ray. H. Whitbeck.

Geonomics.

Wm. M. Tucker (Introduced by Charles R. Dryer.)

The Geography of Columbus, Ohio.

W. W. Atwood.

Educational Advantages of the Regional Treatment of Geography.

Nevin M. Fenneman.

Geography as a Subject of Research.

An analysis of the nature of geographical research. The questions were raised:

What can the geographer do in the field aside from exploration, *i.e.*, what data should he gather first hand?

What kind of research problems await Geography in the case of a well known state like Missouri?

Albert P. Brigham.

Cape Cod and the Old Colony.

The region treated, which is essentially a natural region, includes Cape Cod and the eastward or shoreward parts of Plymouth County. The unity is shown to be physical, historical and industrial.

The physical basis was briefly described with outline of glacial history and topography and the maturing of the shore line.

The historical geography was dealt with by periods. Here we have the period of exploration and early settlement, including most of the seventeenth century; the period of colonial conditions, extending to

the close of the American Revolution; and the federal period. In all the periods the conditions of agriculture and marine activities were outlined.

In the federal period are included; the break up of marine interests at the close of the Revolution; the continuance of general agriculture and home industries; the vast growth of fishing, whaling and world-wide trade down to the Civil War; the decline after the Civil War and the new developments since 1870. The paper also considered, the limiting and localizing of fishing; the specializing of agriculture and manufacture; the development of transportation on sea and land, the changes in population; and the summer industry which is now, and will no doubt remain the dominant factor of subsistence and life in most of the region.

Carl O. Sauer (Introduced by H. H. Barrows.)
Economic Problems of the Ozark Highlands of Missouri.

Alexander G. Ruthven
The Geographic Factors in the Distribution of Animals, with particular reference to the distribution of the land Reptiles of the Davis Mountains Region, Texas. Read by title.

There are several objections to the life-zone theory of distribution which have not been met. The distribution of the land reptiles of the Davis Mountains Region, Texas, shows that the zonal distribution is less than would be expected on the life-zone theory and that there is evidence that other geographic factors than climate are to be recognized. It is suggested that the environmental relations should be considered a complex and that the geographic factors must be determined by ecological and physiological investigation.

Arthur G. Vestal (Introduced by H. C. Cowles.)
The Colorado Mountain Front; Subdivisions North of the Front Range.

The Laramie Range, an uplifted and almost undissected granite peneplain, has for its plant cover a dry grassland with sagebrush. The flat treeless condition continues to the Great Plains, in places without topographic or vegetational break even at the eastern front. Comparison with the Front Range shows that advancement to submature stage of present cycle is accomplished by greater diversity and luxuriance of vegetation.

The Poudre Foothills form the dry, moderately dissected eastern slope of the low mountains north of the Front Range. The outer and lower hills especially have scattered pines and the common shrubs only on upper slopes, with mountain mahogany (a ragged shrub)

on middle slopes. Dry grassland covers basal slopes as well as other slopes and upland flats which are much exposed to sun and wind.

THE POUDRE MOUNTAIN-FRONT, bordering the Poudre Foothills, is exceptional because of two synclinal folds forming embayments of sedimentary rock into the granite. Their relative weakness is responsible for local peneplanation in an early cycle, over their area and that of the adjoining granites. North of the folds there seem to be two mountain-fronts: the outer with cuestas bordering a moderately dissected granite scarp, and with woody foothill vegetation; then flat surface and plains short-grass over the local granite peneplain; then, six miles west of the outer front, a line of monadnocks, with another increase of elevation and again foothills vegetation. The broad northern part of the sedimentary zone bordering the granite is of low dip, giving butte and wide-spaced cuesta topography, with mountain mahogany dotting stony back-slopes and rocky infaces. Numbers of pinyons occur here locally, 130 miles north of their continuous range. Plains short-grass covers fine-soil surfaces of basal slopes, butte-tops, and open troughs between cuestas.

The southern part of the Poudre area has higher, submaturely dissected foothills, bordered by a narrowed sedimentary zone with cuesta-complex of high dip. Pine, mixed shrub, and the less xerophytic types of vegetation are developed almost as in the Front Range.

The writer believes that the details of floristic composition, successional development, relation to immediate ecological factors, and the classification of vegetation-types should find their place in systematic descriptions, which should precede regional description. The latter can thus be devoted to *actual occurrence in space* of the vegetation-types in relation to controlling physical features, and is thus *geographic,* rather than ecological, developmental, floristic, or concerned with classification.

N. A. Bengtson.

The Geographic Unity of Norway (Read by Title.)

Norway is usually referred to as part of Scandinavia and it is seldom thought of as having any right to be considered as a separate geographic province. Its racial and language relations with Sweden and Denmark have caused it to be considered as one of the Baltic countries. The trade changes brought about by war conditions have served to emphasize the fact that Norway is essentially an Atlantic facing country and that it holds an important gateway position for much north-European traffic. Its boundaries, resources, and commercial relations suggest a high degree of geographic unity, a fact which needs to be appreciated by American business if the best commercial interests of Norway and the United States are to be served.

G. E. Condra.
Geography of the Sandhills of Nebraska (Read by Title.)

Ray H. Whitbeck.
Geographic Influences of Lake Michigan on its Opposite Shores: Printed in full herewith.

F. E. Williams (Introduced by R. H. Whitbeck.)
Geographic Influences in Northern Minnesota—Read by Title.

Charles R. Dryer.
The Calumet District of Indiana—Read by Title.

George D. Hubbard and Orville C. Jones.
Some Basic Geographic Principles—Read by Title.

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